# Alternative Materials for Subgrade Modification

## Final Report

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**October 2001**

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16. Abstract

This study examines the laboratory and field performance of two alternative materials used for the modification of unstable (CBR<6) subgrade soils. Modification is temporarily enhancing subgrade stability to improve the constructability of successive pavement layers. The alternative materials included a by-product hydrated lime (BHL) and a Class C fly ash (CCFA) meeting the requirements of AASHTO M 295. Three experimental projects were constructed incorporating these materials with a variety of soil types. The performance of sections treated with these materials was compared to that of control sections treated with a high calcium lime kiln dust (LKD) or dense graded aggregate, depending on site conditions. Information presented in this study includes laboratory background and mix design data, construction procedure evaluation, bearing value and subgrade rut depth data, pavement performance data, and recommended mix design procedures and specifications. The results indicate that BHL and CCFA are acceptable materials for subgrade modification.

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# ALTERNATIVE MATERIALS FOR SUBGRADE MODIFICATION

Experimental Features Project IL96-02

**Final Report**

October 2001

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in cooperation with

Illinois Department of Transportation
Bureau of Materials and Physical Research

This study was supported by the Illinois Department of Transportation Bureau of Materials and Physical Research (BMPR). Laboratory testing was conducted at the BMPR Soils Laboratory. Deflection testing was performed by the BMPR Pavement Technology Unit. Experimental and control sections were constructed using Federal funding according to the requirements of the Federal Highway Administration's Experimental Features program. The assistance and support from Materials and Construction personnel in IDOT Districts 4 and 6 during field test planning and construction is greatly appreciated. Experimental and control sections were constructed by the Dunn Company of Decatur, Illinois. Their cooperation during construction and quality workmanship contributed to the success of this project. Discussions with Riyad Wahab, Geotechnical Engineer at the Bureau of Materials and Physical Research, are also greatly appreciated.

## COVER

Spreading, processing, and compacting CCFA section on US 67 near Jacksonville, Illinois. Photographed by Greg Heckel on October 23, 1997.

## UNITS

Projects constructed as part of this study were constructed using either English or Metric units. Metric units are used except where English units are required. Some useful conversions are shown below.

| | |
|---|---|
| 1 inch = 25 mm | 1 gal./yd² = 4.5 L/m² |
| 3.3 ft = 1 m | 1 lb/yd² = 0.54 kg/m² |
| 1 yd² = 0.84 m² | 1 pcf = 16.02 kg/m³ |
| 1 kip = 4.4 kN | 1 psi = 6.89 kPa |
| (F°-32)/1.8 = C° | 1 ksi = 6.89 MPa |

## COMMON ABBREVIATIONS

| | |
|---|---|
| LKD = Lime Kiln Dust | BHL = By-Product Hydrated Lime |
| CCFA = Class C Fly Ash | DCP = Dynamic Cone Penetrometer |
| IBV = Immediate Bearing Value* | COV = Coefficient of Variation |
| FWD = Falling Weight Deflectometer | |

*IBV is assumed equivalent to the unsoaked CBR (AASHTO T 193) in a laboratory context or the field CBR (ASTM D 4429) when testing in-place subgrade.

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# I. Introduction

## *I.1 Project Overview*

For nearly two decades, the Illinois Department of Transportation (IDOT) has routinely used high calcium lime kiln dust (LKD) to improve the stability of subgrades during construction. In 1994, a major supplier of LKD announced that they would no longer reclaim material from mine storage. Consequently, only the LKD resulting directly from current production was available from that source. Since that time, the price of LKD has more than doubled. Additionally, the supply of LKD has become more restricted while demand continues to increase. The Alternative Materials for Subgrade Modification project was initiated in 1995 to examine alternatives to LKD that may be used to improve subgrade stability.

The work associated with this project was conducted in two phases. Phase One consisted of an in-depth laboratory testing program. The performance of soils treated with the alternative materials was compared to that of corresponding soils treated with LKD. The testing included determining moisture-density relationships, bearing values, compressive strengths, swell potential, and plasticity indices of treated and untreated soils. IDOT Physical Research Report No. 125 (Heckel, 1997) presents the findings of the laboratory study phase of this project.

Phase Two of this project includes the performance evaluations of selected materials in a variety of construction situations. These field evaluations compare experimental sections treated with the alternative materials to control sections treated using standard materials. Phase Two also examines the effectiveness of laboratory mix design procedures in predicting field performance. The treated subgrades have been evaluated based on constructability, bearing values, subgrade rutting, and pavement performance.

This report primarily focuses on the results of Phase Two of this study. The results of the Phase One portion of this study are summarized in Section II.1 of this report.

## *I.2 Field Test Locations*

Three experimental projects were constructed between June of 1997 and April of 1998. These dates reflect when the subgrade was treated and do not reflect when subsequent pavement layers were placed.

Project 1 was constructed in June 1997 on Veteran's Parkway (IL 4) on the north side of Springfield, Illinois. The experimental and control sections are located in the northbound and southbound lanes between J. David Jones Parkway (IL Route 29) and Browning Road.

Project 2 was constructed in October 1997 on the US 67 Expressway west of Jacksonville, Illinois. The experimental and control sections are located in the southbound lanes between the Morton Avenue Interchange (old US 36) and the Liberty Road (Township Road 157) overpass.

Project 3 was constructed in April 1998 on US 34 between Carman Road and the town of Gulfport in western Henderson County, Illinois. The experimental and control sections were located in the westbound lanes.

Maps showing the general locations and details showing the layout of each project are included in Appendix A.

### *I.3 Materials*

Two alternative materials were selected for field evaluation based on their Phase One laboratory performance. One material, by-product hydrated lime (BHL), is the coarse residue which has been separated from the pure, fine hydrated lime during production, commonly called "hydrator tailings." BHL is essentially dirty, coarse hydrated lime. The other material is a Class C fly ash (CCFA) meeting the requirements of AASHTO M 295. The control materials consisted of LKD or dense-graded aggregate (IDOT gradation CA 06) depending on specific site conditions. BHL was provided by the Mississippi Lime Company in Ste. Genevieve, Missouri. CCFA was provided by American Fly Ash from the Commonwealth Edison Will County Station and Iowa-Illinois G & E Louisa Station. Table 1 shows the range of chemical and physical properties of the alternative materials selected for field evaluation. The data ranges shown in Table 1 are based on samples tested during Phase One, during the mix design process, and during test section construction.

Table 1. Chemical and Physical Properties of the Alternative Materials

| | **LKD Control** | **BHL** | **CCFA** |
|---|---|---|---|
| **Chemical Properties** | | | |
| CaO + MgO, % | 81 – 87 | 94 – 114 | 27 – 35 |
| $Ca(OH)_2$, % (Rapid Sugar) | 38 – 49 | 55 – 91 | NT |
| $SO_3$, % | NT | NT | 1 – 3 |
| $SiO_2$, % | NT | NT | 31 – 39 |
| $Al_2O_3$, % | NT | NT | 18 – 23 |
| $Fe_2O_3$, % | NT | NT | 5 – 6 |
| $SiO_2$+$Al_2O_3$+$Fe_2O_3$, % | NT | NT | 55 – 69 |
| Loss on Ignition (LOI), % | 16 – 21 | 15 – 24 | 0.2 – 0.6 |
| | | | |
| **Physical Properties** | | | |
| Specific Gravity (G) | 2.87 – 2.91 | 2.31 – 2.75 | 2.65 – 2.81 |
| + 4.75 mm, % | 0 | 0 | NT |
| + 600 µm, % | 3 – 5 | 1 – 9 | NT |
| + 150 µm, % | 12 – 22 | 46 – 74 | NT |
| + 75 µm, % | NT | NT | 6 – 11 |
| | | | |
| Number of Samples | 4 | 6 | 7 |

NT = Not Tested

The data in Table 1 shows that BHL has the highest variation in overall material properties and is considerably coarser than LKD or CCFA. Table 2 shows the test results from individual BHL samples obtained during lab testing and test section construction.

Table 2. Chemical and Physical Properties of Individual BHL Samples

| | Phase One | Project 1 Mix Design | Project 1 Construction | | Project 2 Construction | |
|---|---|---|---|---|---|---|
| **Chemical Properties** | | | | | | |
| CaO + MgO, % | 94 | 95 | 114 | 99 | 98 | 92 |
| $Ca(OH)_2$, % (Rapid Sugar) | 83 | 91 | 87 | 55 | 70 | 77 |
| Loss on Ignition (LOI), % | 19 | 23 | 24 | 15 | 23 | 17 |
| | | | | | | |
| **Physical Properties** | | | | | | |
| Specific Gravity (G) | 2.46 | 2.31 | 2.35 | 2.75 | 2.48 | 2.50 |
| + 4.75 mm, % | 0 | 0 | 0 | 0 | 0 | 0 |
| + 600 µm, % | 4 | 2 | 2 | 1 | 3 | 9 |
| + 150 µm, % | 54 | 47 | 52 | 50 | 59 | 74 |

The data in Table 2 indicates that the BHL received during construction was not consistent. Data presented later in this Report indicates that this variation did not have a measurable effect on the performance of the test sections evaluated. However, significant variability could potentially be detrimental.

Each field test location featured a different soil type. Both a clay and a silt were treated with BHL and CCFA with LKD used as a control. A sand was treated with CCFA, with a dense-graded aggregate used in the corresponding control section. Table 3 shows the average physical properties of the soils treated in the field test sections.

Table 3. Average Physical Properties of Soils

| | Project 1 | Project 2 | Project 3 |
|---|---|---|---|
| | | | |
| AASHTO Classification | A-6 | A-4 | A-3 |
| IDOT Textural Classification | Clay | Silt | Sand |
| Liquid Limit, % | 39.0 | 29.7 | NT |
| Plasticity Index | 19.6 | 8.0 | NP |
| Sand, % | 0.0 | 0.9 | 97.3 |
| Silt, % | 45.6 | 85.0 | 0.8 |
| Clay, % | 54.4 | 14.2 | 1.9 |
| - 75 µm, % | 100.0 | NT | 1.9 |

NT = Not Tested NP = Non-Plastic

The data shown in Table 3 demonstrates that a wide variety of soil types were tested in the field.

# II. LABORATORY TESTING AND MIX DESIGN

## *II.1 Phase One Laboratory Testing*

The Phase One laboratory testing focused on two alternative lime by-products and two fly ashes. The performance of each material was compared to that of LKD. The lime by-products consisted of a dried lime kiln sludge (DLKS) and BHL. DLKS is produced from a wet kiln exhaust effluent which is ponded as an inert sludge. The effluent is collected, press-dried, and then further dried by activating it with 15% CaO (quicklime). Two Class C fly ashes were used. One ash met the requirements of AASHTO M 295. The other ash had a loss on ignition and sulfate content outside the limits required by AASHTO M 295.

The lime by-products were mixed with three typical Illinois soils in addition to a commercially available, dry-milled Fire Clay. The Fire Clay was included as a readily available, uniform reference soil. Soils were generally treated with 5% lime by-product and 10% fly ash based on the dry weight of soil. Because they were added late in the laboratory study, the fly ashes were only mixed with the Fire Clay.

Laboratory test results indicated that the DLKS and BHL reduced the maximum dry density and plasticity index of the soils in the same manner as the LKD. They also increased the optimum moisture contents, the compressive strengths, immediate bearing values, and the Illinois Bearing Ratio. The tests indicated that DLKS and BHL would perform well as soil modifiers. Test results also indicated that both fly ashes increased the bearing value, compressive strength, and plasticity index of the Fire Clay. Fly ash treatment had no consistent effect on maximum dry density and optimum moisture content. The high sulfate fly ash treated Fire Clay exhibited a tendency to swell when soaked during the Illinois Bearing Ratio test. Curing prior to soaking significantly reduced swelling.

The Phase One study recommended that DLKS, BHL, and Class C fly ash meeting AASHTO M 295 requirements be evaluated in the field. Prior to initiating field tests, the producer of DLKS withdrew the material from consideration due to the high costs associated with production. These production costs would not have made DLKS a competitive alternative to LKD. Complete laboratory test data and analyses are included in Physical Research Report No. 125 (Heckel, 1997).

## *II.2 Mix Design Procedures*

Prior to construction, a project-specific determination of the optimum treatment rate for each alternative material was made by IDOT's Bureau of Materials and Physical Research (BMPR). In general, representative samples of soils from the three field test locations were taken to the BMPR soils laboratory along with samples of each alternative material to be used. A separate mix design was not performed for specific LKD control sections. Mix designs for LKD modified soils are based on overall project soil conditions. Additionally, IDOT has adequate experience with LKD, lessening the need for mix designs.

Mix design procedures involved developing a moisture-density-immediate bearing value (IBV) relationship over a range of moisture contents for each trial treatment rate. Individual batches of treated soil at specific moisture contents were prepared by mixing dry soil, BHL or CCFA, and the water required to obtain the desired moisture content. Each batch of BHL treated soil was allowed to mellow in a sealed container for one hour prior to compaction. Compaction of each batch of CCFA treated soil was also delayed for one hour to simulate the maximum allowable field compaction delay. After one hour, the treated soil was compacted in a 100 mm diameter mold according to AASHTO T 99 Method C.

After compaction and prior to removing the compacted specimen from the mold, the treated soil was penetrated using a standard CBR piston according to AASHTO T 193. The load at a penetration of 5 mm was used to determine the CBR. The CBR obtained using these procedures is considered equivalent to the IBV. After penetration, the treated soil was removed from the mold and oven dried to determine actual moisture content.

After recording the appropriate data, plots of dry density vs. moisture content and IBV vs. moisture content were prepared at each trial treatment rate for each alternative material. The treatment rate that indicated a minimum IBV of 10 at the anticipated field moisture contents was selected. The actual field treatment rate was generally increased by 1% to offset construction loss.

The mix design procedure for fly ash modified soils included an optional provision for curing up to 48 hours. The curing could be used in lieu of adding additional fly ash to obtain the required IBV. Curing was done at room temperature by sealing the compacted specimen in the mold and delaying penetration.

In addition to curing, the fly ash mix design included special procedures for granular soils. Instead of relying on IBV tests for evaluating fly ash treated granular soils, compressive strength testing was considered more effective (refer to Section II.3, Project 3 for a discussion about granular soil mix design). Cylindrical samples were prepared at standard dry density and optimum moisture content for each trial fly ash content. They were allowed to cure for 24 hours at room temperature and were then tested according to AASHTO T 208. The treatment rate which resulted in a minimum compressive strength of 310 kPa was selected.

An effective moisture content range was also determined. The minimum effective moisture content is equal to the optimum moisture content of the treated soil. The maximum effective moisture content is the highest moisture content that can sustain a minimum IBV of 10.

## *II.3 Mix Design Results*

The results from each project's mix designs are summarized below. Appendix B contains the complete test data obtained during each mix design. All treatment rates shown in the following sections are percentages based on the maximum dry density of the untreated soil.

<u>Project 1 – Clayey Soil</u>

The mix design performed for Project 1 determined that 3% BHL and 10% CCFA treatment rates would meet stability requirements. An additional 0.5% of BHL and 1.0% of CCFA was added to offset construction losses. Figure 1 shows the IBV profile determined during the mix design.

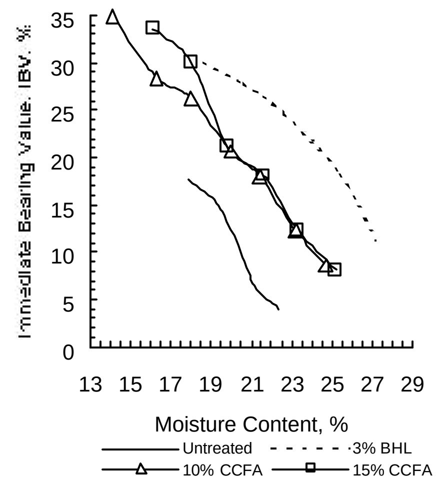


Figure 1.  Project 1 IBV Profile

The IBV data plotted in Figure 1 shows that the addition of 3% BHL provided the greatest benefit.  The BHL increased the IBV over a wider range of moisture contents than the CCFA.  Figure 1 also shows that 15% CCFA produced a slight increase in IBV over the 10% CCFA at moisture contents less than about 20%.  Beyond that, there was virtually no change in the IBV-moisture content relationship for the soil treated with 10% and 15% CCFA.

Project 2 – Silty Soil

A comprehensive mix design was not completed for Project 2.  The location of the test section was changed approximately one month prior to construction.  A mix design had already been completed using soil from the originally planned location.  The soil at the new location had a higher silt fraction and less than half the PI of the soil at the original location (Appendix B includes soil properties).  Additionally, the original test plan did not include the use of BHL.  BHL was added to the plan at the same time the location was changed.

Construction scheduling required a treatment rate recommendation before a new, comprehensive mix design could be completed.  The recommendation for a 15% CCFA treatment rate and 48 hour curing period was based on the original mix design, and the recommendation for a 4% BHL treatment rate was based on previous laboratory testing and field experience.  The CCFA treatment rate was increased from 15% to 16% to offset construction variances.  No allowance for construction variance was added for the BHL.

Project 3 – Sandy Soil

The mix design for Project 3 determined that a 12% CCFA treatment rate would provide adequate subgrade stability in conjunction with a 24 hour curing period.  Figure 2 shows the IBV profile obtained from the Project 3 mix design.

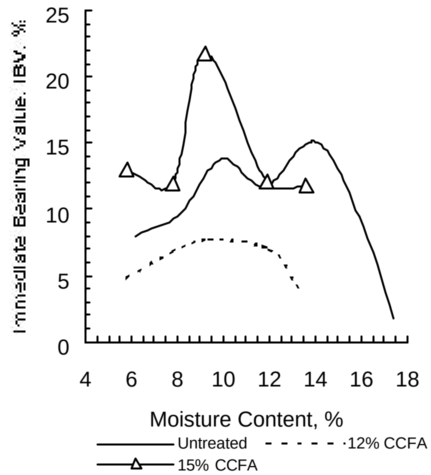


Figure 2.  Project 3 IBV Profile

The data in Figure 2 shows a significant increase in IBV at optimum moisture content (9.3%) for the soil treated with 15% CCFA.  After reducing the treatment rate to 12%, the IBV decreased to below that of the natural soil.  Such a decrease in IBV is contrary to expected behavior.  An additional IBV sample of soil treated with 12% fly ash was prepared at optimum moisture content.  This sample was allowed to cure in a plastic bag at room temperature for 24 hours.  Curing the sample resulted in an IBV equal to 45.

The atypical IBV test results for the soil treated with 12% fly ash shown in Figure 2 and the unreasonably high cured IBV cast doubt on the validity of an IBV based mix design process for sandy soils.  Therefore, compressive strength tests were performed to confirm IBV test results.  According to a correlation between IBV and cohesion commonly used by IDOT (IDOT, 1982), an IBV of 10% is approximately equal to an unconfined compressive strength of 310 kPa.  Samples of fly ash treated soil were compacted at standard dry density and optimum moisture and allowed to cure in plastic bags at room temperature for 24 hours, 48 hours, and 7 days.  The soil treated with 12% fly ash achieved an average compressive strength of 396 kPa after 24 hours.  This strength corresponded to an IBV of 13.

The recommended application rate of 12%, with a minimum 24 hour curing period, was based on the compressive strength.  The effective moisture content range of 9.2% to 10.2% was based on the moisture-density relationship of the treated soil.  No IBV data was used to determine the recommended application rate or effective moisture content range.

# III. TEST SECTION CONSTRUCTION

## *III.1 General*

An Experimental Feature Work Plan was prepared and approved as required by the Federal Highway Administration prior to construction. The Work Plan was amended as additional test sections were added. Test section locations were selected based, primarily, on the availability of suitable construction projects planned within two years of Work Plan approval.

On each project, samples of soil were obtained from random locations over the length and width of the untreated test and control sections for laboratory classification. The classification test results were used to confirm the uniformity of soil types within the control and experimental sections.

The experimental and control modified subgrade sections on Project 1 were constructed June 3-5, 1997. On Project 2, the sections were constructed October 23-24, 1997. On Project 3, the experimental section was constructed on April 21, 1998. Project 3's dense-graded aggregate control section was constructed at the end of April 1998. Subsequent pavement layers were constructed as shown in Section III.9, Table 5.

Selected photographs of construction operations are included in Appendix C.

## *III.2 Subgrade Preparation*

Subgrade modification generally does not require extensive subgrade preparation, beyond completing construction to the approximate required plan and grade. Current IDOT specifications require lightly scarifying or disking the surface prior to distributing material. Scarification enables the equipment used to mix the soil and modifier to more easily break down cohesive soils to a suitable size. Most contractors, however, find it more practical to distribute material prior to scarifying or disking. Distributing material prior to scarification enables spreading equipment to more easily traverse the area to be treated, resulting in a more uniform distribution of material.

Experimental and control sections on Projects 1 and 2, consisting of clays and silts, were scarified to a depth of 150 mm following the distribution of LKD and BHL. The CCFA section on Project 1 was scarified in conjunction with the addition of water approximately 18 hours prior to CCFA distribution. Scarification was accomplished with a Caterpillar 140G motor grader with a five tooth scarifier. The CCFA section on Project 2, which consisted of silt, was not scarified because distribution had to be accomplished using the two-step process described in Section III.4. The CCFA section on Project 3, which consisted of sand, was not scarified.

Modification often requires more water for a chemical reaction than what is available in the subgrade prior to treatment. In these cases, the contractor may elect to add water either before or after material distribution. When water is added after CCFA distribution, it should be done directly in front of the mixing equipment. On Project 1, water was added 18 hours prior to CCFA distribution to allow the water to soak into the cohesive soil. On Project 3, water was added to the sandy soil approximately four hours prior to CCFA distribution.

### *III.3 Material Handling*

On Project 1, BHL and CCFA were delivered to the project site in pneumatic tank trailers. Material was blown from pneumatic tanks into a portable, covered hopper. From the hopper, the material was transferred into spreader trucks using an auger-type conveyor system. The hopper had its own air filtration system to control the amount of dust lost to blowing. However, blowing dust was generated by the free-fall of material from the auger outlet to the bed of the spreader truck. LKD was delivered to the Project 1 site in covered dump-bed trailers. LKD was dumped in piles directly on the subgrade and was transferred to spreader trucks using a wheel loader.

On Project 2, LKD and CCFA were delivered to the project site in covered dump-bed trailers. The materials were dumped in piles directly onto the subgrade and were transferred to spreader trucks using a wheel loader. BHL was delivered in pneumatic tank trailers and was placed onto the subgrade directly from the pneumatic tank.

On Project 3, CCFA was delivered to the site in pneumatic tank trailers. CCFA was stockpiled in a staging area located away from the test section. CCFA was transferred from the stockpile to the spreader trucks using a wheel loader.

In general, the use of BHL caused personnel safety concerns for the contractor. The high CaO content of BHL causes a burning sensation when the dust comes in contact with skin and eyes. Breathing can also be difficult and painful. The contractor's personnel covered their skin with clothing and gloves to minimize skin contact. They also made use of simple dust masks. Respirators were tried, but were not used because the dust would accumulate at the seal between the skin and the mask causing irritation. The personnel were also instructed to keep away from the dust as much as possible. The workers on-site said that working with LKD, while causing some discomfort, does not have the same severe problems with personal contact.

### *III.4 Spreading Material*

With the exception of Project 2's BHL section, material was spread using modified tandem trucks. The truck bed consisted of an elongated hopper with a conveyor system at the base. The conveyor fed material at a constant rate from the hopper into a baffle system mounted to the back of the truck. The baffles evenly distributed material over the width of the truck (about 2.4 m). The correct application rate was obtained by spreading a known quantity over a known area.

The existing subgrade conditions on Project 1 did not impact spreading operations. Spreader trucks were able to distribute material without excessive rutting or mobility problems.

On Project 2, existing subgrade conditions varied from firm and moist on the LKD and BHL sections to weak and wet on the CCFA section. BHL was spread directly onto the subgrade from pneumatic tanker trucks. A motor grader was then used to uniformly distribute the BHL over the surface of the subgrade. Spreader trucks were used to distribute the LKD and CCFA. No problems were experienced during the BHL or LKD spreading operations.

The large quantity of CCFA on Project 2 required that spreading and mixing operations be in two stages, to ensure a homogeneous mixture of soil and fly ash. Thirty percent or 36 kg/m² of the total CCFA quantity was initially distributed using spreader trucks. The CCFA test section contained a 50 m long soft, wet area. The initial spreading operation resulted in extensive, severe rutting within this area. The rut depth was measured as much as 380 mm. A motor grader was used twice to pull out stuck spreader trucks. Due to the excessive rutting and mobility difficulties, obtaining a uniform initial distribution of CCFA was not possible. After mixing the initial CCFA quantity and smoothing the surface with a motor grader, the remaining CCFA was spread using the spreader trucks. The trucks did not experience significant problems during stage two spreading, resulting in a uniform distribution of the remaining quantity of CCFA.

On Project 3, the spreader trucks had extreme difficulty spreading CCFA. The trucks lost traction on the sand before completely spreading their loads. The rotary speed mixer was frequently used to rescue spreader trucks, greatly reducing productivity. Severe subgrade rutting prevented a uniform distribution of CCFA. After spreading CCFA over 20% of the test section area, the contractor altered spreading procedures in an effort to increase productivity and minimize disturbance of the subgrade. The contractor used the rotary speed mixer to pull the spreader trucks over the length of the test section. Instead of one truck spreading the required quantity of CCFA over a small area, five spreader trucks distributed their loads in a 2.4 m wide strip over the length of the test section. This was repeated until the entire width of the test section was treated. Additional fly ash was spread in the areas damaged by the initial spreading operation to offset the poor uniformity.

Table 4 shows the as-built treatment rates. The data is based on the total quantity of material delivered, the area treated, and the maximum dry density of the untreated soil. The data assumes a uniform distribution was obtained and there were no losses. It is estimated between 0.5 and 1.0% of material was not incorporated as a result of material handling or minor over-spreading outside the required treatment area.

Table 4. As-Built Treatment Rates

| | LKD | | BHL | | CCFA | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Project 1 – Clay | 4% | 21 kg/m² | 3% | 17 kg/m² | 11% | 57 kg/m² |
| Project 2 – Silt | 7%[a] | 37 kg/m² | 5%[a] | 26 kg/m² | 20%[a] | 107 kg/m² |
| Project 3 - Sand | - | - | - | - | 13% | 66 kg/m² |

Treatment rate is shown as a percent of the untreated soil dry weight and as kg of material added per square meter of subgrade.

[a] Approximate rate based on maximum dry density of a similar soil outside the test area.

## *III.5 Processing*

The contractor used a CMI RS-500 rotary speed mixer to process the modifier and subgrade soil on all three projects. The RS-500 is configured with a 2.4 m wide mixing drum in the center of the machine. The mixing drum is fitted with rows of teeth and can rotate over a range of speeds. The size of the mixing chamber can also be adjusted to achieve the desired processed material size. The mixing drum can be raised and lowered depending on the desired depth of processing. Figure 3 depicts the operation of the RS-500 rotary speed mixer.

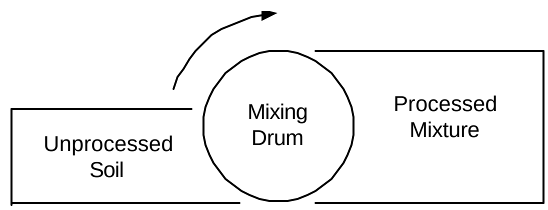


Figure 3. RS-500 Processing Operation

LKD, BHL, and CCFA were mixed to a depth between 300 and 350 mm. Approximately 18 L/m² of water was spread directly in front of the RS-500 for LKD and BHL treated soils. The BHL section of Project 1 required an additional 27 L/m² of water to offset dry subgrade conditions. Additional water was also distributed directly in front of the RS-500 on the Project 1 CCFA section.

A homogeneous mixture of modifier and soil was generally obtained after one pass of the RS-500. The rotational speed of the RS-500 mixing drum was set between 170 and 200 rpm depending on site conditions. The contractor varied the forward speed of the RS-500 in an effort to maintain a homogeneous mixture. Generally, faster drum speeds and slower forward speeds were required to sufficiently mix treated cohesive soils. The contractor allowed BHL treated soils on Project 1 to mellow for 24 hours after initial mixing. The contractor then reprocessed and compacted the BHL treated soil. The contractor also elected to use a forward and reverse pass of the RS-500 on LKD and BHL treated soils on Project 2.

## *III.6 Compaction*

Compaction was performed using one Hyster C850B or C852B vibratory roller. These models are equipped with a single smooth or sheep's foot drum. The sheep's foot drum was used on cohesive soils on Projects 1 and 2, and the smooth drum was used to compact the sand-CCFA mixture on Project 3. The rollers' vibratory mode was used on all three projects.

BHL treated soil required a minimum 24 hour mellowing period between initial processing and compaction. The 24 hour mellowing period allows the coarse BHL particles sufficient time to completely hydrate. This is especially important in situations where the existing subgrade is moist or dry and additional water needs to be added. Laboratory testing indicated that insufficient hydration prior to compaction may cause excessive drying of the treated soil (Heckel, 1997). The excessive drying may cause the treated soil to lose cohesion and increase the percentage of unbound, silt sized particles. As a result, there can be an increased potential for frost heave. The BHL-soil mixture was compacted 36 hours after initial processing on Project 1. On Project 2, the BHL-soil mixture was compacted three hours after mixing. The 24 hour mellowing period was not completed because wet subgrade conditions along with the forecast for rain were thought to be sufficient to completely hydrate the BHL.

CCFA treated soils required compaction to be completed within one hour of mixing. This limitation is due to the "flash set" characteristics of the cementitious reaction between CCFA and water. Compaction after 1 hour can begin to break down the cementitious bonds developing in the CCFA-soil mixture. The longer compaction is delayed, the lower the resulting strength (Ferguson and Zey, 1990). The roller generally began compaction directly behind the RS-500. The forward speed of the RS-500 was about the same as that of the roller, but the roller made 6 to 8 vibratory passes and 1-3 static passes over a given section depending on project conditions. Periodically, the RS-500 had to briefly stop and wait for the roller to catch up to maintain a satisfactory compaction delay. The time between the completion of mixing and the completion of compaction ranged from 20 to 45 minutes for all three projects. An additional smooth drum vibratory roller was used on Project 3 to increase productivity. The requirement to compact treated soils within one hour of mixing did not significantly reduce productivity or cause a hardship for the contractor.

LKD treated soils were compacted immediately following mixing.

### *III.7 Finishing and Curing*

Following compaction, a motor grader smoothed and shaped the LKD and BHL sections to seal the surface and promote drainage. Based on the contractor's previous experience on private sector CCFA modification projects, no construction equipment was allowed on the section for 18 to 24 hours following compaction. CCFA sections on Projects 1 and 2 were rough graded in the same manner as the LKD and BHL sections.

Project 2's CCFA section required 48 hours of curing. Due to a poor weather forecast and contractor scheduling conflicts, rough grading was attempted prior to the end of the curing period. While grading the CCFA treated section about 18 hours after compaction, small surface cracks began to form under the weight of the grader. Grading was stopped, and after about 6 hours the contractor attempted grading again. This time while the grader was working, a 15 mm wide longitudinal crack formed between the rear wheels of the grader. The crack was probably formed by tensile forces created as the soil heaved up between the wheel loads of the grader. The grading operation was stopped to avoid further damage. The contractor was not required to finish grading after the curing period. Enough grading had been completed to allow water to drain off of a majority of the CCFA modified soil.

Project 3 required a 24 hour curing period following compaction of CCFA treated soils based on the mix design. No water was added during the curing period due to precipitation. The surface of the treated subgrade was moist with isolated dry spots 17 hours after compaction. Construction equipment was not allowed on the section during the curing period. The CCFA section did not require rough grading because a smooth drum roller was used for compaction.

### *III.8 Climatic Conditions*

The chemical reactions required to achieve satisfactory performance are dependent upon temperature. For lime treated soils, the soil temperature must be above freezing. The effects of temperature are more critical for CCFA treated soils. A low temperature slows CCFA hydration and higher temperatures may cause "flash set" conditions. For CCFA treated soils, other research [Ferguson, 1990; Glogowski et al, 1992; McManis, 1988] has identified 4.5°C as a lower limit for soil temperature. Projects 2 and 3 were constructed at average soil temperatures of 8°C and 9°C, respectively.

The ambient air temperature during curing CCFA modified soils is also an important consideration. On Project 2, temperatures fluctuated between 16°C and 4°C, with an average temperature of 10.5°C. On Project 3, temperatures fluctuated between 20°C and 6.7°C, with an average temperature of 12°C.

Precipitation during construction is also a concern for CCFA modification. If a significant rainfall event occurs after the CCFA has been spread, but before it has been processed, the CCFA will hydrate prematurely. Wetting CCFA prior to processing causes hydration and cementation to occur before any benefits are realized.

### *III.9 Pavement*

Each project had varying pavement designs. With the exception of Project 2, pavements were constructed, in the same construction season, within three months of subgrade improvement. Table 5 includes pavement cross-section information and paving dates.

Table 5. Pavement Information

| Pavement Layer | Project 1 | Project 2 | Project 3 |
|---|---|---|---|
| | | | |
| Date Paved | September 1997 | August 1998 | June 1998 |
| Pavement | 340 mm Full-Depth Bituminous Concrete | 250 mm Jointed Concrete | 330 mm Full-Depth Bituminous Concrete |
| Subbase | None | 100 mm Cement-Aggregate Mixture (IDOT CAM II) | None |
| Plan Improved Subgrade | 300 mm Modified Soil | 300 mm Modified Soil | 300 mm Dense Graded Aggregate |

On Project 2, a subgrade investigation prior to modification identified an area of extremely unstable subgrade corresponding to the control and experimental sections. This area required 600 mm of improved subgrade to meet Department subgrade stability requirements. The bottom 300 mm of improved subgrade was modified with LKD, BHL, or CCFA. The following year, 300 mm of dense graded aggregate was placed on top of the modified soil layer prior to paving.

# IV. TEST SECTION PERFORMANCE

## *IV.1 General*

The primary purpose of the treated subgrade layer is to provide a uniformly stable construction platform. The subgrade must not rut more than about 12 mm under construction traffic. It must also provide a solid platform onto which successive layers of paving materials may be placed and adequately compacted when required. The treated subgrade layer is not considered in the pavement design. The pavement is designed based on untreated subgrade conditions. Therefore, a treatment that provides long-term stability after construction is not required.

The material or method used to treat the subgrade should not create a situation where the treated subgrade becomes a detriment to pavement performance. Such situations can include creating a frost susceptible material or initiating a chemical reaction that creates expansive by-products.

The performance evaluation for the three projects has been separated into two sections. The first section discusses the quality of the improved subgrade as a stable construction platform. The second section discusses the performance of the finished pavement over a period of approximately three years.

Every reasonable effort was made to maintain the integrity of the results obtained during field testing. The stability of the subgrade prior to and after construction was determined using the same methods for each experimental and LKD treated control section. Initial and subsequent testing was performed at the same locations, where possible. Variations in climatic conditions between projects that may affect performance were recorded. Random samples of LKD, BHL, and CCFA were obtained and analyzed for each project to verify the quality of the materials used.

## *IV.2 Improved Subgrade Quality*

### IV.2.1 Constructability

The experimental sections were constructed using equipment that is typically used to construct LKD treated subgrades throughout Illinois. There are no significant differences in material handling procedures, except for the concern regarding the irritation caused by BHL dust. According to the Contractor's personnel, BHL causes significantly more irritation than LKD or CCFA. The construction methods for LKD and BHL treatment are nearly identical, except for the BHL using a larger quantity of water and needing a conditioning period prior to compaction. The construction methods for CCFA and LKD treated soils are generally similar, except for a compaction delay limitation, two stage spreading and processing for large CCFA quantities, and a 24-hour curing period. With the differences in construction methods, productivity was not greatly impacted. Productivity can be improved for CCFA treatment by adding a second roller. This enables the rotary speed mixer to maintain standard productivity without needing to wait for compaction.

Using a rotary speed mixer to process soil, modifier, and water achieves a high quality, homogeneous mixture. This is especially important for CCFA treated soils, which depend on a good distribution of CCFA particles throughout the soil matrix to achieve adequate cementation.

### IV.2.2 Moisture Content

Each material used to treat the subgrade depends on water to initiate a chemical reaction that improves the stability of the treated soil. The CaO present in lime-products reacts with water to form $Ca(OH)_2$. The $Ca(OH)_2$ creates free cations which fuels the cation exchange necessary for the immediate flocculation and agglomeration of clay particles within the soil matrix. The $Ca(OH)_2$ also combines with clay silicas and aluminas to fuel a pozzolanic reaction which cements soil particles (TRB, 1987). The higher percentage of CaO present in the BHL increases the amount of water needed to completely hydrate the material. CCFA is a self-cementing material, which means it does not depend on a reaction with any particular constituent of the soil. The immediate strength gain in fly ash can be attributed to the reaction of tricalcuim aluminate (Ferguson 1985) and the portion of CaO existing as tricalcium silicates (McManis, 1988), similar to portland cement. If there is an insufficient amount of water available to completely hydrate the CCFA, cementation may not be complete enough to provide the desired results.

Because of the importance of having a sufficient amount of water available to completely hydrate the treated materials, field moisture contents were obtained before, during, and after treatment. These moisture contents were compared to the effective moisture content range determined during the mix design process. Samples of soil were obtained at depths between 75 and 150 mm and were transported to the lab in sealed plastic bags. Tables 6 and 7 summarize BHL and CCFA moisture content data. The effective moisture ranges shown in the tables are based on mix design data. All moisture contents shown in this report were determined in the laboratory according to AASHTO T 265. Moisture content data was obtained from LKD treated soils 4 to 7 days after compaction. These LKD moisture contents were approximately equal to the BHL moisture contents obtained at the same time.

Table 6. Summary of BHL Moisture Data

| | Project 1- Clay Moisture Content | Project 2 - Silt Moisture Content |
|---|---|---|
| Effective Moisture Range | 24 – 27 % | Not Determined |
| Untreated | 20.2 % | 24.1 % |
| After Processing | 25.2 % | 18.9 % |
| After Compaction – Same Day | No Sample | 16.9 % |
| 4 – 7 Days After Compaction | 23.0 % | 23.7[a] % |

[a] There was 18 mm of precipitation ± 3 days prior to sampling.

The data in Table 6 indicates the BHL was generally within the effective moisture content range after processing. The effective moisture content range for Project 2, although not determined in a laboratory, probably consisted of lower moisture contents based on previous experience with silty soils. After compaction, moisture contents were below the effective moisture content range for the clay soil on Project 1, indicating hydration was probably still occurring after compaction. On Project 2, precipitation elevated the post compaction moisture content, but the moisture content immediately after compaction shows a moisture content that is probably below the effective range. Additional water should probably have been added on Project 2 during processing.

Table 7. Summary of CCFA Moisture Data

| | Project 1 - Clay Moisture Content | Project 2 - Silt Moisture Content | Project 3 - Sand Moisture Content |
|---|---|---|---|
| Effective Moisture Range | 20 – 24 % | 18 – 24 %[a] | 9.2 – 10.2 % |
| Untreated | 22.9 %[b] | 24.1 % | 10.7 %[b] |
| After Processing | No Sample | 20.5 %[c] | 7.2 % |
| After Compaction – Next Day | No Sample | 12.3 % | 7.4 % |
| 4 – 7 Days After Compaction | 20.0 % | 21.1 %[d] | No Sample |

[a] Based on mix design for a soil similar to that treated.
[b] Does not include water added to the subgrade before spreading CCFA.
[c] Moisture content after stage 1 processing. No sample was obtained after stage 2 processing.
[d] There was 18 mm of precipitation approximately 3 days prior to sampling.

The data in Table 7 indicates that the addition of CCFA at the required treatment rates significantly reduces the water available for hydration. Actual reductions ranged from 3.5% on Project 3 to 11.8% on Project 2. The theoretical amount of reduction was determined using simplified weight-volume relationships. The untreated weight of water and solids at standard dry density and optimum moisture content were held constant. The weight of CCFA was added to the weight of solids and the moisture content was recalculated. The resulting predicted reduction in moisture contents ranged from 1.5% to 2.6%, much less than what actually occurred. The actual average moisture reduction was 3.2 times the predicted reduction. The following equation has been developed to estimate the actual moisture reduction on a given project. Because the equation is based on only three projects with significant data scatter, moisture loss error limits of about 2% should be applied to the results.

$$\text{Moisture Loss, \%} = 3.2 \times \{OMC - [100W_w / (W_s + W_{CCFA})]\}$$

Where: $OMC$ = Optimum moisture content of the untreated soil in percent.
$W_w$ = OMC/100 multiplied by the standard dry density in kg/m$^3$ (pcf)
$W_s$ = Standard dry density in kg/m$^3$ (pcf) / 1 m$^3$ (1 ft$^3$)
$W_{CCFA}$ = Treatment rate per m$^3$ in kilograms (rate per ft$^3$ in pounds)

The equation may be used as a guideline to determine how much additional water, if any, is required to keep the CCFA-soil mixture within its effective range. Low moisture contents on Project 3 may have contributed to the poor performance discussed in Section IV.2.6.

Nuclear density gages were also used to determine moisture contents. Samples of soil were always obtained at nuclear test locations for laboratory moisture determination. The moisture contents from nuclear testing were an average of 3.7% lower than the laboratory moisture contents, which are shown in this report. Therefore, laboratory moisture content determinations should always be made to identify the appropriate correction factor to apply to the nuclear moisture content data.

### IV.2.3 Density

Compacted moisture content and density were determined using either a Troxler Model 3401 or 3440 nuclear gage capable of 300 mm direct transmission. The tests were performed according to AASHTO T 310. Samples of soil were taken from a depth of 75 to 150 mm at each test location for laboratory moisture determination according to AASHTO T 265. The laboratory moisture tests were used to check moisture contents and correct the density obtained using the nuclear gage, if necessary.

The compacted density of the treated subgrade is not generally a good indicator of subgrade stability. Density requirements may be met, but stability may still be poor. For example, Project 3 densities were generally greater than 98% of standard dry density, but stability was not satisfactory as discussed in Section IV.2.6. The compaction methods employed by the contractor generally achieved a minimum density of 95% of the standard dry density of the treated soil, as required by IDOT Standard Specifications, with one area on Project 3 achieving 93% compaction. The area corresponded to the area of lowest moisture content.

### IV.2.4 Bearing Values

The dynamic cone penetrometer (DCP) was used to determine the IBV of the treated and untreated soils. The number of blows required to advance the DCP cone in increments of 150 mm was recorded. The DCP test was not conducted on frozen soils. The IBV was determined based on the South African correlation between field CBR and DCP penetration rate (Mauer and deBeer, 1988). For field subgrade evaluation purposes, IBV is assumed to be equivalent to the field CBR.

The IBV was generally obtained to a depth of 450 mm. Data corresponding to the top 300 mm are included in this report. DCP tests were generally obtained at 50 meter intervals along each control and test section. On Project 1, DCP tests were typically located on the centerline of the northbound or southbound lanes. On Projects 2 and 3, a DCP test was conducted in the approximate center of both the driving and passing lane. Additional tests were conducted as needed to more accurately characterize the subgrade performance. IDOT subgrade stability policy requires a minimum IBV of 8 prior to placing subsequent pavement layers.

Average IBV data for each section within each project is summarized in Figures 4 through 13. The graphs plot average IBV and the coefficient of variation (COV) versus the number of days after compaction. IBV and COV data from the top 150 mm and the bottom 150 mm of the treated subgrade have been separated. The COV is a measure of the variability of the data relative to the average value. The average COV of the overall DCP results is 0.47. COVs greater than 0.47 indicate above average variability, and COVs less than 0.47 indicate below average variability. Appendix D includes the results of individual DCP tests.

Figures 4 –7 show Project 1 IBV and COV results.

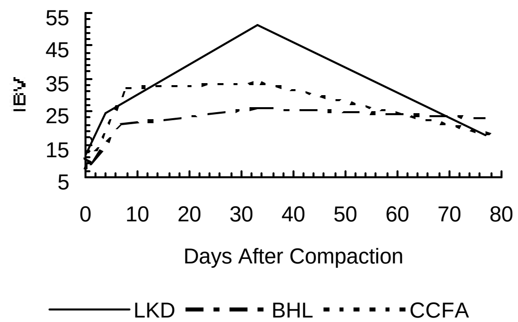


Figure 4. Project 1 Average IBV vs. Days After Compaction: 0 to 150mm.

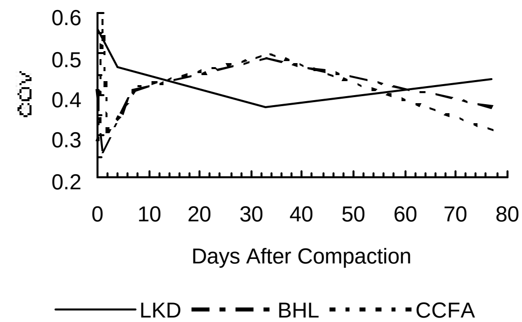


Figure 6. Project 1 COV vs. Days After Compaction: 0 to 150 mm.

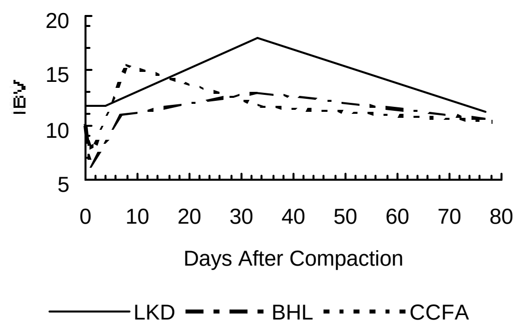


Figure 5. Project 1 Average IBV vs. Days After Compaction: 150 to 300 mm.

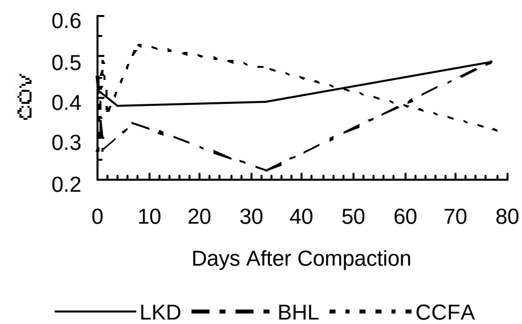


Figure 7. Project 1 COV vs. Days After Compaction: 150 to 300 mm.

Figure 4 shows that the top 150 mm of treated subgrade meets requirements after one day for all materials. However, Figure 5 shows the IBV of the bottom 150 mm of treated subgrade actually declines or stays the same after treatment. For the bottom 150 mm, the IBV of the LKD treated soils shows no improvement for four days, while the IBV of BHL and CCFA treated soils require approximately six days to regain their untreated IBV. Figures 4 and 5 also show that IBV increases in the first 10-30 days after compaction before leveling off. CCFA treated soils appear to reach peak IBV sooner than LKD and BHL treated soils. Over time, however, IBVs of each section tended to decline. The last test series, approximately 77 days after compaction, indicates LKD, BHL, and CCFA treated soils exhibit nearly the same IBV. Overall, the IBV data indicates that BHL and CCFA treated soils demonstrate performance comparable to that of LKD treated soils.

The COV data shown in Figures 6 and 7 indicates that all materials produce roughly equivalent variability. The COV for the top 150 mm shown in Figure 6 shows lower variability between products relative to the COV data for the bottom 150 mm shown in Figure 7.

Figures 8 – 11 show Project 2 IBV and COV data.

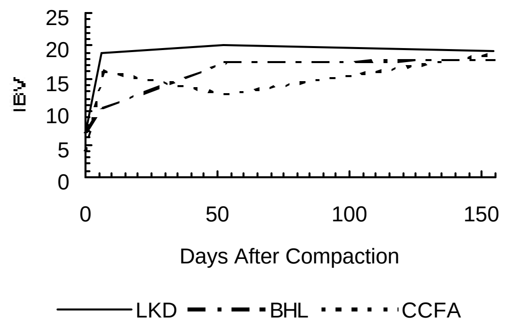


Figure 8. Project 2 Average IBV vs. Days After Compaction: 0 to 150 mm.

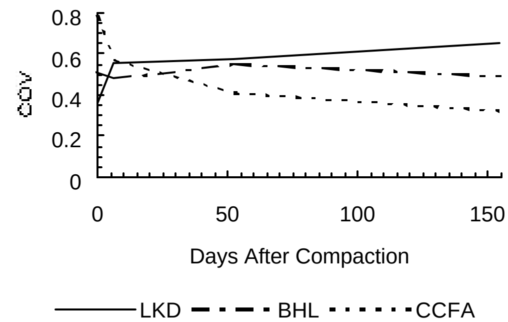


Figure 10. Project 2 COV vs. Days After Compaction: 0 to 150mm.

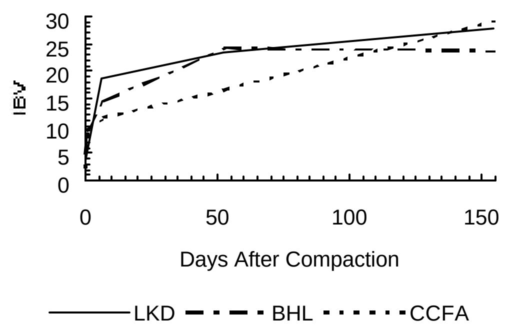


Figure 9. Project 2 Average IBV vs. Days After Compaction: 150 to 300 mm.

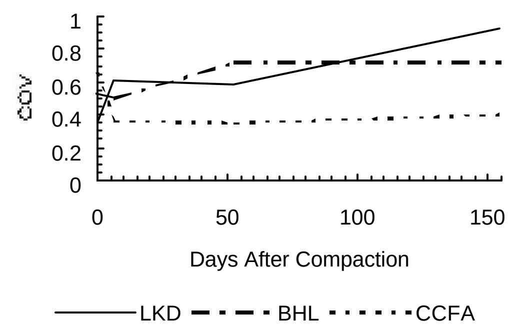


Figure 11. Project 2 COV vs. Days After Compaction: 150 to 300 mm.

The data in Figures 8 and 9 shows that LKD, BHL, and CCFA treatment increased the IBV to acceptable levels within five days of treatment. The data shows that LKD and BHL performed satisfactorily despite the natural soil having clay contents of less than 20%. The treated sections were not covered during the winter but did not experience a significant reduction in IBV. Overall, the IBV data indicates that BHL and CCFA treated soils demonstrate acceptable performance comparable to that of LKD treated soils.

The data in Figures 10 and 11 shows that CCFA treated soils were generally less variable than the LKD and BHL treated soils.

Figures 12 and 13 show Project 3 IBV and COV data.

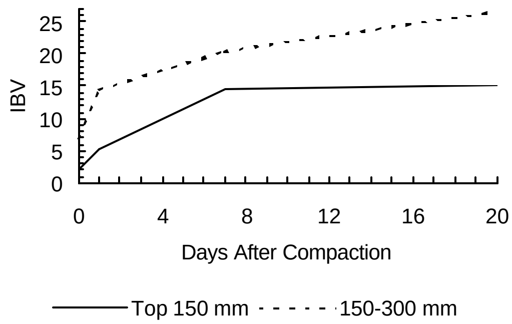


Figure 12. Project 3 Average IBV vs. Days After Compaction for CCFA Treated Subgrade.

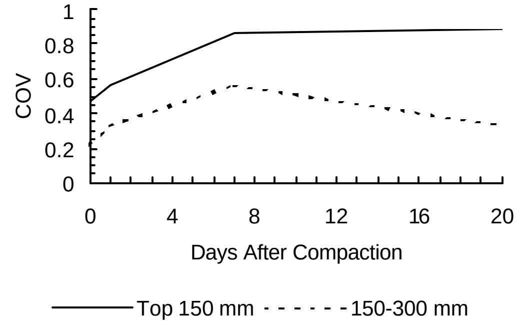


Figure 13. Project 3 COV vs. Days After Compaction for CCFA Treated Subgrade.

The data in Figure 12 seems to indicate that CCFA treatment achieved satisfactory IBVs after about four days. However when the data from Figure 13 is examined, the COV for the top 150 mm of treated subgrade is the highest of any section within this study. Figure 14 shows an IBV profile that separates the IBV data into single data points to clarify variability.

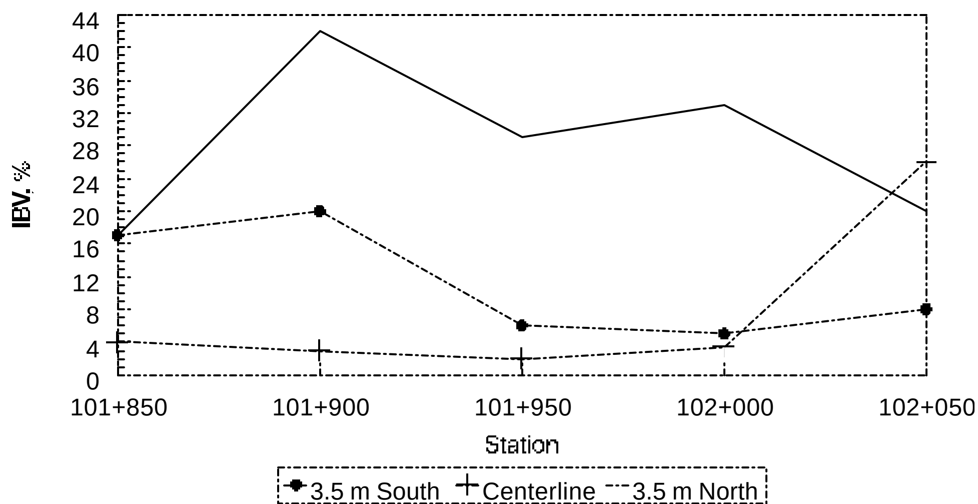


Figure 14. Project 3 IBV of the Top 150 mm of Treated Soil after 7 Days

The data in Figure 14 shows that CCFA treated soils beneath the proposed passing lane did not attain satisfactory IBVs. The combination of exceptionally good and exceptionally poor performance causes the misleading representation of results shown in Figure 12. The cause of the poor CCFA performance and the required remedial action is discussed in Section IV.2.6.

## IV.2.5 Visual Observations and Rutting

Project 1

No direct observations of rutting were made for Project 1 as part of this study. However, IDOT District 6 Resident Engineer, Mark Riegel, indicated that subgrade problems were not encountered during construction of the full-depth bituminous pavement.

Project 2

Rutting observations on Project 2 were made on May 13, 1998. Rutting of the BHL and LKD sections was observed using a loaded tractor-trailer truck weighing 323.5 kN. The truck turned, backed, and moved forward to simulate movements expected during paving. The truck also made four straight passes in the same wheel-path. The resulting rut depths ranged from 0 to 25 mm.

Rutting of the CCFA section was observed using a loaded tandem axle truck weighing approximately 240 kN. The truck was unable to simulate paving movements because the contractor placed ditch debris down the center of the CCFA section. The truck made 10 straight passes in the same wheel path. Generally rut depths ranged from 0 to 75 mm with isolated locations with up to 150 mm ruts. Appendix C includes selected photographs of rutting on Project 2.

The apparent excessive rut depths probably resulted from leaving the treated subgrade unprotected during the winter. Frost action resulted in a density reduction of the top 25 to 50 mm of subgrade. The isolated deep ruts on the CCFA section may have also been influenced by the presence of wet ditch debris. A bulldozer was pushing the debris around on the CCFA section prior to testing, disturbing the surface of the treated subgrade.

Overall, the performance of treated soils under load confirmed the DCP data which indicated that satisfactory IBVs had been maintained below the material affected by frost action. The rutting that did occur was probably a result of frost action and the presence of wet ditch material. It is not a reflection of poor performance.

Project 3

Seven days after compaction, visual observations of the condition of the CCFA treated subgrade indicated variable performance over the length of the section. Some areas performed extremely well. These areas were visibly cemented. Other areas did not show visible improvement. These areas were characterized by loose sand, no apparent cementation, and isolated areas with no visible fly ash.

Rutting of the treated subgrade was observed seven days after compaction using a loaded tandem axle truck weighing approximately 230 kN. The truck turned, backed, and moved forward to simulate movements expected during paving. Rut depths ranged between 0 and 75 mm. The rut depth data, along with the DCP data summarized in Section IV.2.4, indicates high variability. Appendix C includes selected photographs of rutting on Project 3. Figure 15 combines the IBV data and rutting observations showing the areas not meeting minimum stability requirements over the 12 m wide and 300 m long CCFA test section.

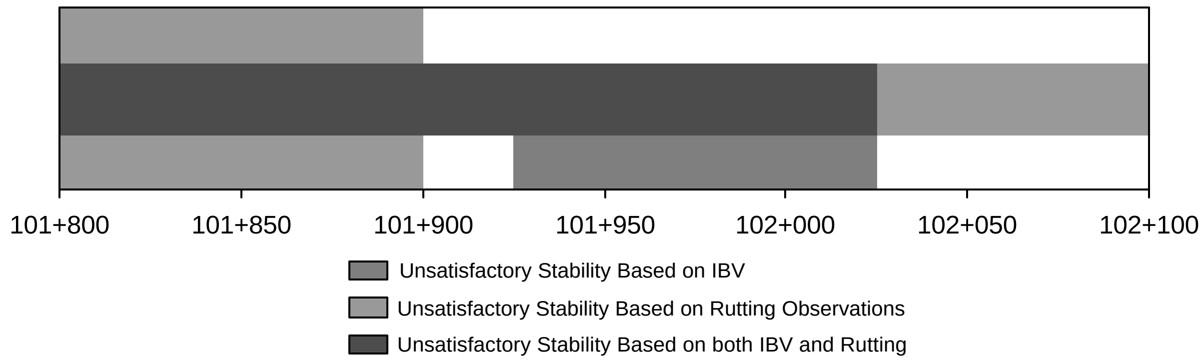


Figure 15. Areas Showing Unsatisfactory Stability on Project 3.

The subgrade rutting data shown in Figure 15 verifies the unsatisfactory DCP results along the centerline. The data also verifies the acceptable DCP results at locations offset 3.5 m from centerline. The data shows areas that obtained acceptable DCP IBVs did not necessarily perform well under load. The inability of a practical DCP test program to identify all unsatisfactory locations within an area subject to variable performance may have contributed to this inconsistency.

### IV.2.6 Project 3 Remedial Action and Analysis of Unsatisfactory Performance

The CCFA treated sand on Project 3 did not uniformly meet minimum IBV and rutting requirements as discussed in Sections IV.2.4 and IV.2.5. The areas which performed well demonstrated that CCFA can be used successfully to modify a sand. However, the overall unsatisfactory performance of this section required remedial action to improve IBVs to satisfactory levels.

The top 150 mm of CCFA treated subgrade was removed over the full width and length of the experimental section. The CCFA treated subgrade was replaced with 150 mm of dense graded aggregate. The bottom 150 mm of CCFA treated subgrade was left in place.

An unpublished report (Heckel, 1998) examines the field data and construction procedures for Project 3 in detail. The report includes a determination of the approximate CCFA content of the treated sand. The difference between the gradation of the sand and fly ash made it possible to determine the approximate amounts of fly ash added. The untreated soil was well graded medium to fine sand with an average of 1.9 % material finer than 0.075 mm. The COV of the untreated sand finer than 0.075 mm data was 0.37, indicating good uniformity. The fly ash contained an average of 91% material finer than 0.075 mm.

The estimated fly ash contents were calculated by subtracting the average untreated percent finer than 0.075 mm from the total percent finer than 0.075 mm. Since fly ash is finer than 0.075 mm, the additional fines should correspond to the approximate amount of fly ash added. Locations that performed well contained 12 to 14 percent CCFA. Locations that performed poorly contained 6 to 8 percent CCFA.

The report finds that the most likely primary cause of the test section's poor performance was non-uniform distribution of CCFA. Due to the large amount of CCFA being spread, a visual evaluation of uniformity is difficult. A non-visual method of checking uniformity would be more appropriate. For example, a lath could be used as a probe to randomly check the depth of distributed CCFA. Low moisture content and variable density may have had a minor role in causing the poor performance. The method of estimating moisture loss described in Section IV.2.2 should be used to ensure that an adequate quantity of water is available for hydration.

### *IV.3 Pavement Performance*

The performance of the finished pavement was monitored for approximately three years. The monitoring focused on determining if the alternative materials had an adverse effect on pavement performance. Annual pavement distress surveys were performed on each project. The final surveys were conducted in October 2000. The only distress identified was in the BHL section of Project 1. At Station 209+30 NB, an area approximately 4 meters long and 1.5 meters wide was milled shortly after paving to remove an uneven section of pavement. The defect was not attributed to the BHL treatment. There was no difference in ride quality between the control and test sections.

The falling weight deflectometer (FWD) was used on Projects 1 and 3 to identify the modulus of subgrade reaction ($E_{RI}$). The testing was performed by the Bureau of Materials and Physical Research using a Dynatest 8000 FWD. The $E_{RI}$ was calculated using the University of Illinois procedure. Deflections were normalized to a 40 kN load. Tests were conducted at approximately 15 – 20 meter intervals in both the control and experimental sections. The FWD was not used on Project 2 because 300 mm of dense graded aggregate was placed on top of the modified soil prior to constructing the jointed concrete pavement. The resulting depth to subgrade would have made characterization with the FWD uncertain. Figures 16 and 17 summarize the FWD data.

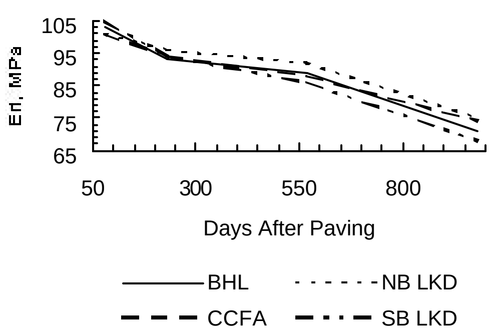


Figure 16. Project 1 $E_{RI}$ vs. Number of Days after Paving.

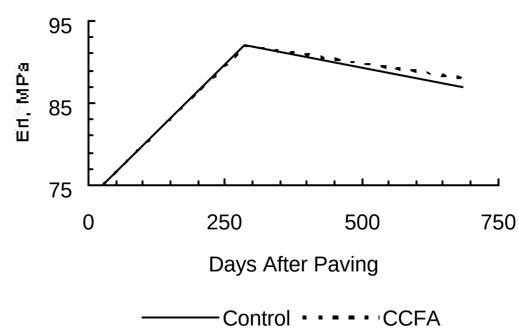


Figure 17. Project 3 $E_{RI}$ vs. Number of Days after Paving.

The data in Figures 16 and 17 show that the BHL, CCFA, and control sections performed similarly. Based on available empirical correlations, an $E_{RI}$ of 60 MPa is equivalent to an IBV of about six. The first data point shown on Figure 17 was obtained during the summer. The high pavement temperature (45°C) of the full depth bituminous pavement had a significant effect on the normalized deflections used to calculate $E_{RI}$. All other test data was obtained in the fall or spring months with the highest pavement temperature being 22°C. Appendix E includes a complete FWD data summary.

The distress surveys and FWD data indicate that the use of BHL and CCFA did not compromise pavement performance.

# RECOMMENDATIONS

The field and laboratory testing results indicate that BHL and CCFA are acceptable alternatives to LKD for subgrade modification. BHL and CCFA increase subgrade IBV and decrease rutting during construction. Pavements with subgrades modified with LKD, BHL, and CCFA showed no measurable difference in performance over the three year monitoring period.

Although it performs well with clayey soils, CCFA modification is more appropriate for soil types, such as silt and sand, that do not respond to lime treatment. CCFA modification would generally be less expensive than removing and replacing these soils with dense graded aggregate. For clayey soils, the CCFA treatment rate will be approximately two to three times the corresponding LKD treatment rate. In these situations, the material and transportation cost differences between CCFA and LKD (or BHL) are likely to significantly influence the product selection.

Because of its coarse particle size, BHL requires a significant amount of water to completely hydrate. Ideally, BHL should be used where the existing subgrade is extremely wet to minimize the amount of water the contractor is required to add.

The high treatment rates required for successful CCFA modification make it difficult to visually assess the uniformity of CCFA application. A probe should be used to randomly measure the depth of CCFA during spreading. This is especially important for granular soils which depend solely on the cementitious properties of the CCFA. The performance of CCFA treated granular soils is also dependent on the availability of a sufficient amount of water to complete hydration. The empirical formula shown in Section IV.2.2 may be used to estimate the amount of moisture reduction resulting from the addition of CCFA.

BHL modification mix designs may be performed according to existing IDOT LKD modification mix design procedures. The use of BHL requires a new material specification and minor revisions to IDOT's existing Standard Specification for Lime Modified Soils. New mix design procedures and construction specifications have been developed for Fly Ash Modified Soils.

CCFA experimental sections used fly ash that met AASHTO M 295 requirements for use in concrete. Certain chemical and physical requirements for fly ash when used in concrete may not apply when it is used as a soil modifier. For example, available alkalies, strength activity index, and soundness may have no bearing on the performance of fly ash modified soil. Additionally, the maximum limits for loss-on-ignition (LOI), MgO, and material retained on the 0.045 mm sieve may be too restrictive. The use of Class C fly ash that does not meet these AASHTO requirements could potentially reduce material costs and increase the number of fly ash sources available. Additional lab testing or field trials should be conducted to characterize the effects, if any, of modifying soil with Class C fly ash that does not meet AASHTO M 295 LOI, MgO, or fineness requirements.

Recommended mix design procedures, material specifications, and construction specifications are included in Appendix F.

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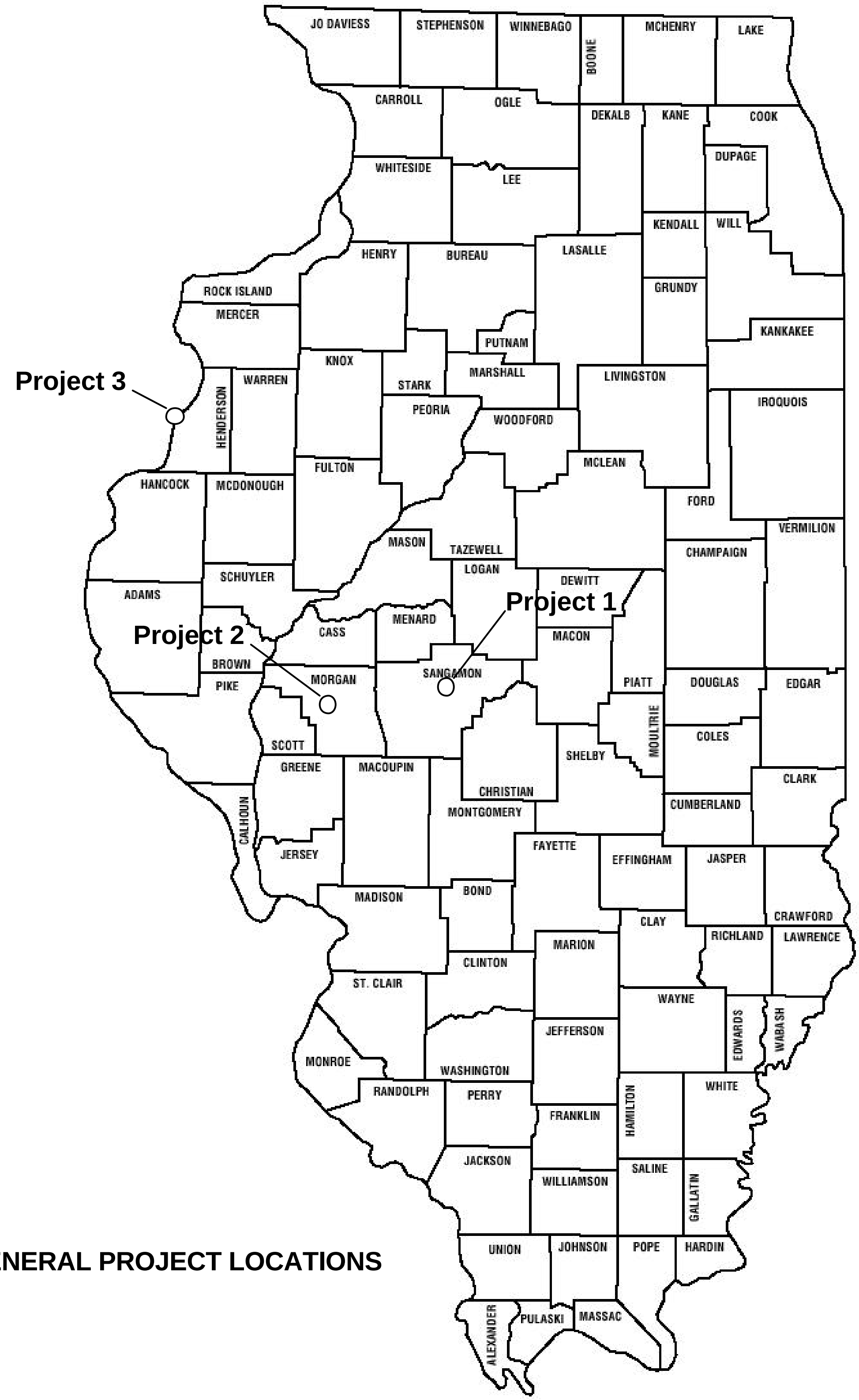
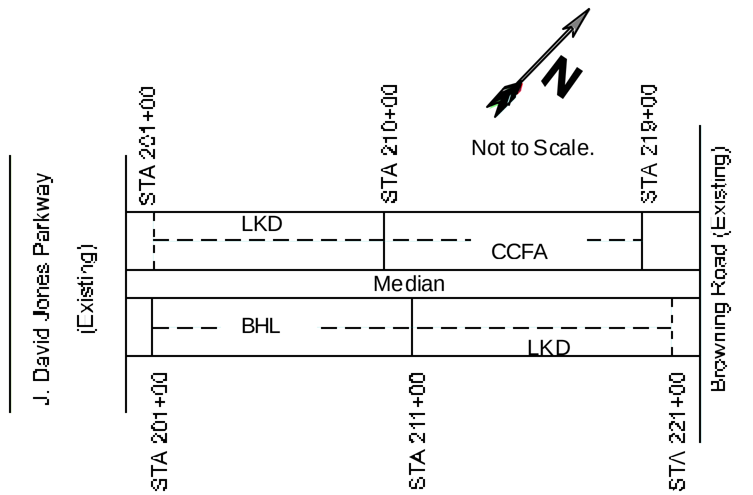
## Appendix A

## Project Location and Section Layout Information

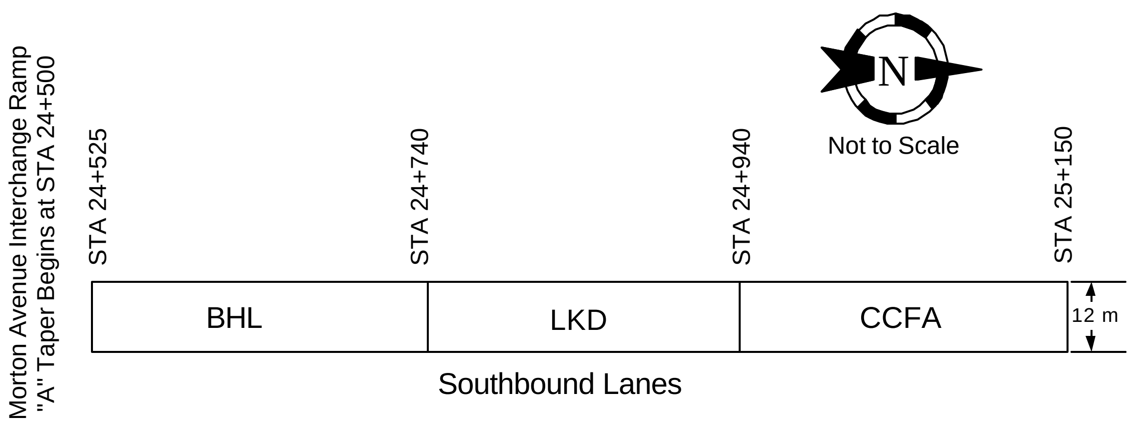



**GENERAL PROJECT LOCATIONS**

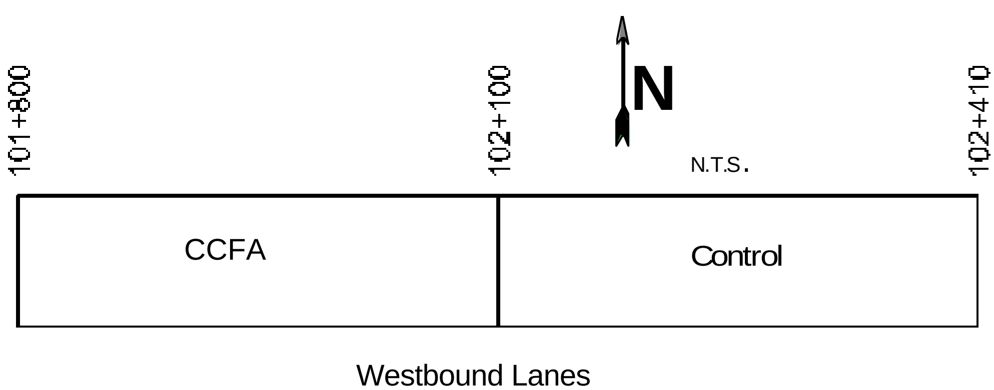
## TEST SECTION LAYOUTS




**Project 1**




**Project 2**



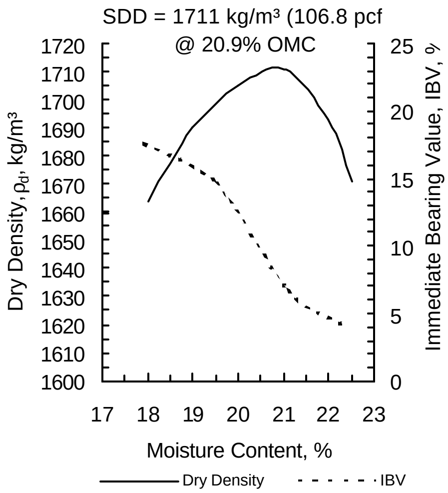

**Project 3**

# Appendix B

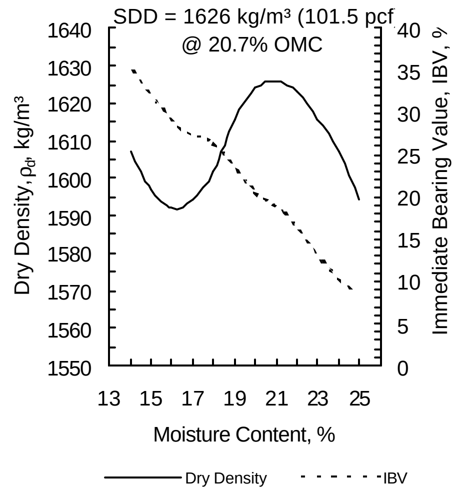
# Mix Design Information

## Project 1 Mix Design

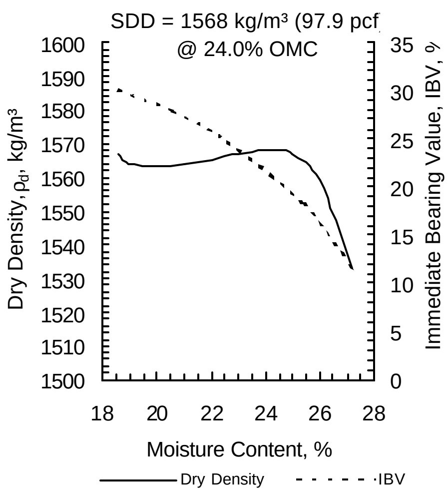
### Moisture-Density-IBV Relationships and IBR Data



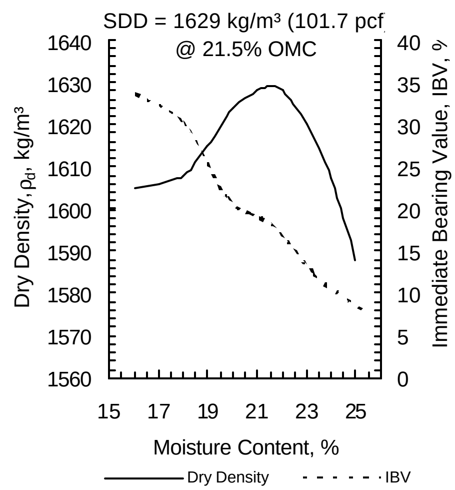

**Untreated Clay**




**Clay Treated with 10% CCFA**




**Clay Treated with 3% BHL**




**Clay treated with 15% CCFA**

### Illinois Bearing Ratio Test Results

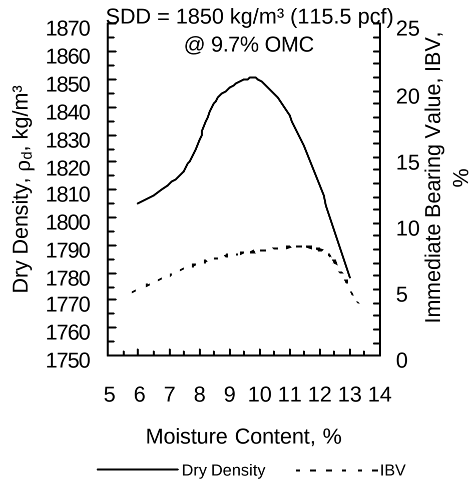
| | IBR, % | Swell, % | Molded Dry Density, kg/m³ | Molded MC, % | Change in Dry Density, kg/m³ | Change in MC, % |
|---|---|---|---|---|---|---|
| | | | | | | |
| Untreated | 2.3 | 2.6 | 1689 | 21.2 | -40 | +2.1 |
| 3% BHL | 16.1 | 1.3 | 1586 | 22.8 | -21 | +2.5 |
| 10% CCFA | 8.3 | 3.7 | 1616 | 21.0 | -64 | +4.9 |

## Project 2 Mix Design

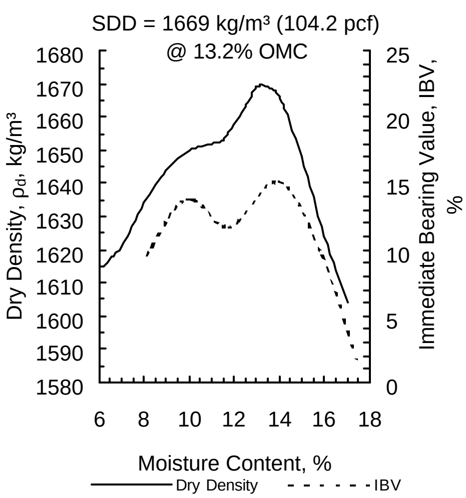
A complete CCFA mix design was performed in June 1997. Prior to construction, the test section was moved to another location on the same project. A new complete mix design was not performed, but a new moisture-density-IBV relationship was developed for the new conditions. No mix design was performed for BHL treated soils. The original mix design data is included below along with the moisture-density-IBV relationship representing actual field conditions.

| | Original Location | Final Location |
|---|---|---|
| Textural Class. | SiCL | Silt |
| AASHTO Classification | A-6(11) | A-4 |
| LL | 38.2 | 27.6 |
| PI | 17.4 | 4.9 |
| Sand, % | 0.5 | 1.5 |
| Silt, % | 77.2 | 87.8 |
| Clay, % | 22.2 | 10.8 |
| -75 µm, % | 99.5 | - |
| SpG | 2.707 | - |

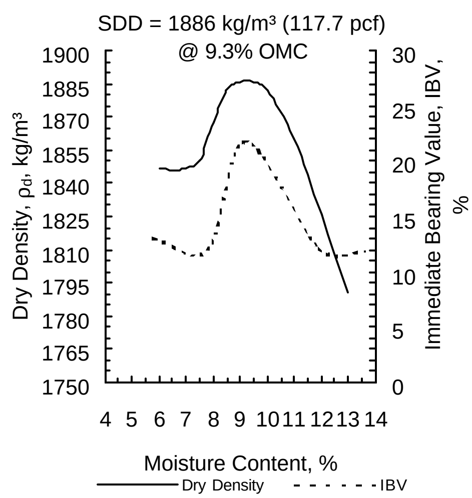
**Untreated Soil Classification Data**



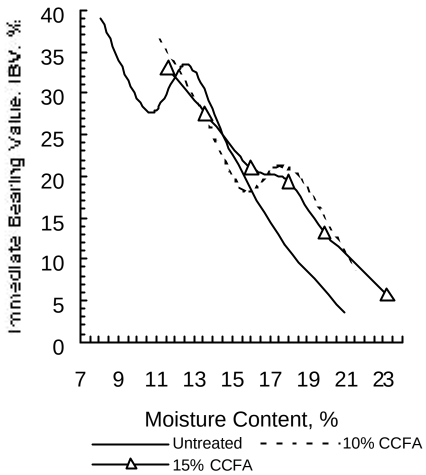

**Original Location SiCL Treated with 10% CCFA**



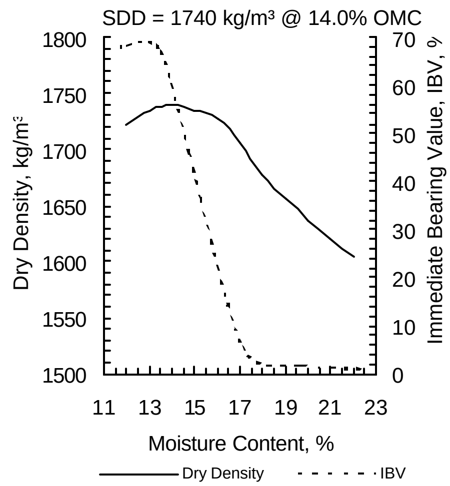

**Original Location Untreated SiCL**




**Original Location SiCL Treated with 15% CCFA**




**Original Location SiCL IBV Profile**




**Final Location Silt Treated with 15% CCFA**

**Original Location SiCL Cured IBV at a 24% Moisture Content**

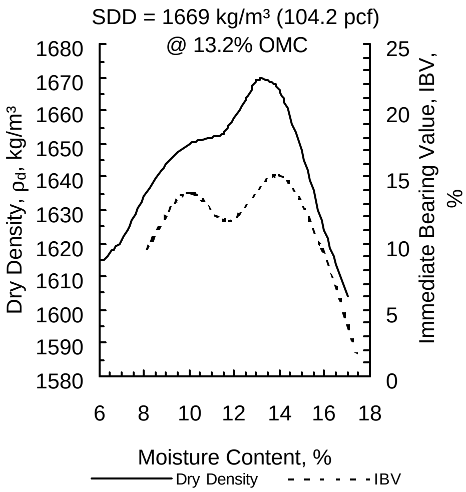
| Curing Time | 10% CCFA IBV, % | 15% CCFA IBV, % |
|---|---|---|
| | | |
| 24 hours | 6.0 | 8.7 |
| 48 hours | 7.4 | 10.6 |

**Original Location SiCL Illinois Beaing Ratio Test Results**

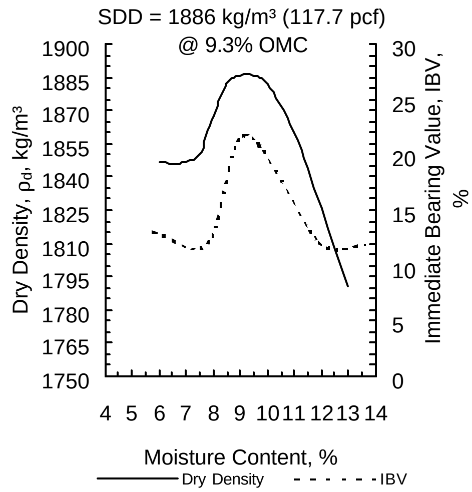
| | IBR, % | Swell, % | Molded Dry Density, kg/m³ | Molded MC, % | Change in Dry Density, kg/m³ | Change in MC, % |
|---|---|---|---|---|---|---|
| | | | | | | |
| Untreated | 6.9 | 0.1 | 1742 | 16.8 | -11 | +2.6 |
| 15% CCFA | 32.1 | 0.0 | 1690 | 17.9 | -3 | +2.4 |

## Project 3 Mix Design

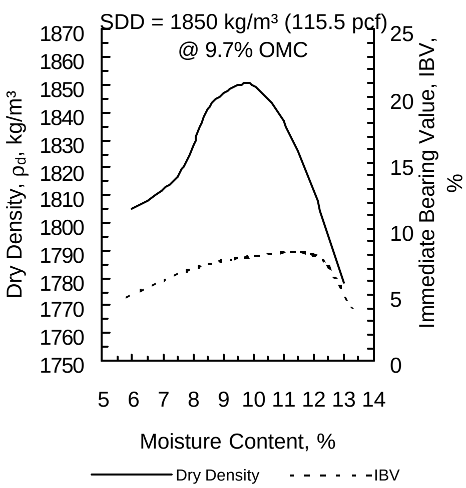
## Moisture-Density-IBV Relationships




**Untreated Sand**




**Sand Treated with 15% CCFA**




**Sand Treated with 12% CCFA**

### Cured IBV at a 9.6% Moisture Content

| Curing Time | 12% CCFA IBV, % |
|---|---|
| | |
| 24 hours | 45 |

### Illinois Beaing Ratio Test Results

| | IBR, % | Swell, % | Molded Dry Density, kg/m³ | Molded MC, % | Change in Dry Density, kg/m³ | Change in MC, % |
|---|---|---|---|---|---|---|
| | | | | | | |
| 12% CCFA | 140 | 0.0 | 1847 | 9.8 | +11 | +2.1 |

## Compressive Strength Test Results

| TREATMENT | CURING | $q_u$, kPa | $\varepsilon_u$, % | Dry Density, $\rho$, kg/m$^3$ | MC, % | % of $\rho_{dmax}$ | % of OMC |
|---|---|---|---|---|---|---|---|
| 12% CCFA | 24 Hours | 448 | 1.4 | 1866 | 9.5 | 100.1 | 98.0 |
| | | 347 | 1.0 | 1836 | 9.4 | 99.2 | 97.0 |
| | | 389 | 1.3 | 1850 | 9.6 | 100.0 | 99.0 |
| | | 402 | 1.4 | 1846 | 9.6 | 99.8 | 99.0 |
| 12% CCFA | 48 Hours | 453 | 1.4 | 1862 | 9.3 | 100.1 | 95.9 |
| | | 412 | 1.4 | 1841 | 9.9 | 99.5 | 102.1 |
| | | 378 | 1.3 | 1836 | 9.7 | 99.2 | 100.0 |
| | | - | - | - | - | - | - |
| 12% CCFA | 7 Days | 486 | 1.2 | 1855 | 8.8 | 100.3 | 90.7 |
| | | 377 | 1.4 | 1825 | 9.2 | 98.6 | 94.8 |
| | | 543 | 1.6 | 1850 | 9.9 | 100.0 | 102.1 |
| | | 423 | 1.7 | 1860 | 9.6 | 100.5 | 99.0 |
| 15% CCFA | 24 Hours | 661 | 1.1 | 1902 | 9.3 | 100.8 | 100.0 |
| | | 435 | 1.1 | 1842 | 9.3 | 97.7 | 100.0 |
| | | 599 | 0.9 | 1894 | 9.4 | 100.4 | 101.1 |
| | | 504 | 1.3 | 1862 | 9.0 | 98.7 | 96.8 |
| 15% CCFA | 48 Hours | 615 | 1.5 | 1878 | 9.2 | 99.6 | 98.9 |
| | | 673 | 1.5 | 1895 | 9.3 | 100.5 | 100.0 |
| | | 552 | 2.0 | 1882 | 8.9 | 99.8 | 95.7 |
| | | 505 | 1.1 | 1846 | 9.1 | 97.9 | 97.8 |
| 15% CCFA | 7 Days | 618 | 1.5 | 1865 | 8.5 | 98.9 | 91.4 |
| | | 599 | 1.5 | 1873 | 8.5 | 99.3 | 91.4 |
| | | 813 | 1.9 | 1913 | 8.1 | 101.4 | 87.1 |
| | | 755 | 1.8 | 1903 | 8.1 | 100.9 | 87.1 |

# Appendix C

## Selected Photographs


RS-500 Processing CCFA Treated Clay on Project 1

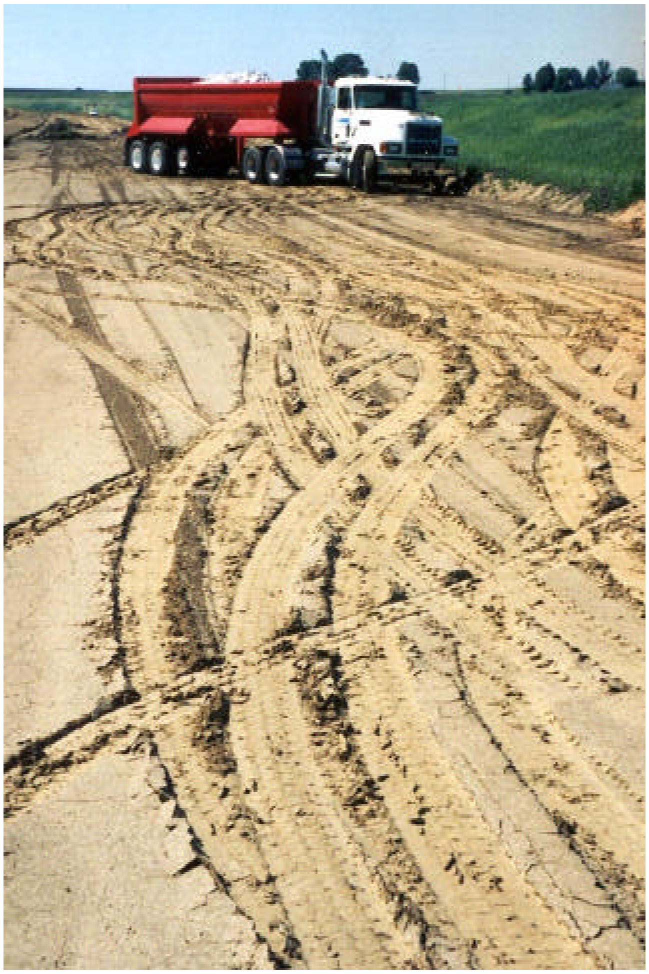
Adding Water and Processing BHL Treated Silt on Project 2

Spreading of Stage I CCFA on Project 2


Subgrade Rutting While Spreading Stage I CCFA on Project 2

Spreading, Processing, and Compacting Stage II CCFA on Project 2

Tandem Axle Truck Loading CCFA Treated Soil on Project 2



Tractor-Trailer Truck Loading LKD Section on Project 2

Spreader Truck Stuck While Spreading CCFA on Project 3

Processing and Compacting CCFA Treated Sand on Project 3

Tandem Axle Truck Loading CCFA Treated Subgrade with Resulting Ruts on Project 3

# Appendix D

## Individual DCP Test Data

## Project 1 DCP Test Summary

### Control Section

| Station | Approximate Test Location | Test Date | Description | IBV 0-150 mm | IBV 150-300 mm |
|---|---|---|---|---|---|
| | | | | | |
| 203+00 SB | CL | 6-2-97 | Untreated | 20 | 19 |
| 205+00 SB | CL | 6-2-97 | Untreated | 11 | 12 |
| 205+00 SB | 3 m LT | 6-2-97 | Untreated | 9 | 9 |
| 207+00 SB | CL | 6-2-97 | Untreated | 12 | 10 |
| 207+00 SB | 3 m RT | 6-2-97 | Untreated | 8 | 6 |
| 209+00 SB | CL | 6-2-97 | Untreated | 8 | 10 |
| 209+00 SB | 3 m RT | 6-2-97 | Untreated | 7 | 10 |
| 207+00 SB | CL | 6-6-97 | 4 Days A.C. | 14 | 8 |
| 213+00 NB | CL | 6-5-97 | 4 Days A.C. | 35 | 15 |
| 215+00 NB | CL | 6-6-97 | 4 Days A.C. | 23 | 7 |
| 217+00 NB | CL | 6-6-97 | 4 Days A.C. | 13 | 10 |
| 219+00 NB | CL | 6-6-97 | 4 Days A.C. | 23 | 14 |
| 203+00 SB | CL | 7-8-97 | 33 Days A.C. | 38 | 23 |
| 207+00 SB | CL | 7-8-97 | 33 Days A.C. | 65 | 13 |
| 203+00 SB | CL | 8-20-97 | 77 Days A.C. | 17 | 10 |
| 205+00 SB | CL | 8-20-97 | 77 Days A.C. | 22 | 15 |
| 207+00 SB | CL | 8-20-97 | 77 Days A.C. | 15 | 10 |

SB = Southbound Lanes  NB = Northbound Lanes  CL = Centerline  A.C. = After Compaction

### BHL Section

| Station | Approximate Test Location | Test Date | Description | IBV 0-150 mm | IBV 150-300 mm |
|---|---|---|---|---|---|
| | | | | | |
| 203+00 NB | CL | 6-2-97 | Untreated | 5 | 6 |
| 205+00 NB | CL | 6-2-97 | Untreated | 9 | 14 |
| 207+00 NB | CL | 6-2-97 | Untreated | 14 | 9 |
| 209+00 NB | CL | 6-2-97 | Untreated | 11 | 7 |
| 203+00 NB | CL | 6-6-97 | 1 Day A.C. | 8 | 5 |
| 203+00 NB | 3 m LT | 6-6-97 | 1 Day A.C. | 8 | 5 |
| 205+00 NB | CL | 6-6-97 | 1 Day A.C. | 11 | 8 |
| 207+00 NB | CL | 6-6-97 | 1 Day A.C. | 8 | 6 |
| 209+00 NB | CL | 6-6-97 | 1 Day A.C. | 10 | 5 |
| 203+00 NB | CL | 6-12-97 | 7 Days A.C. | 13 | 7 |
| 205+00 NB | CL | 6-12-97 | 7 Days A.C. | 28 | 14 |
| 207+00 NB | CL | 6-12-97 | 7 Days A.C. | 17 | 7 |
| 209+00 NB | CL | 6-12-97 | 7 Days A.C. | 22 | 13 |
| 203+00 NB | CL | 7-8-97 | 33 Days A.C. | 36 | 15 |
| 207+00 NB | 3 m RT | 7-8-97 | 33 Days A.C. | 9 | 9 |
| 207+00 NB | 3 m LT | 7-8-97 | 33 Days A.C. | 36 | 15 |
| 209+00 NB | CL | 7-8-97 | 33 Days A.C. | 23 | 13 |
| 203+00 NB | CL | 8-20-97 | 77 Days A.C. | 32 | 17 |
| 205+00 NB | CL | 8-20-97 | 77 Days A.C. | 12 | 12 |
| 207+00 NB | CL | 8-20-97 | 77 Days A.C. | 26 | 8 |
| 209+00 NB | CL | 8-20-97 | 77 Days A.C. | 22 | 5 |

## Project 1 DCP Test Summary (cont.)

## CCFA Section

| Station | Approximate Test Location | Test Date | Description | IBV 0-150 mm | IBV 150-300 mm |
|---|---|---|---|---|---|
| | | | | | |
| 213+00 SB | CL | 6-2-97 | Untreated | 7 | 11 |
| 213+00 SB | 3 m RT | 6-2-97 | Untreated | 5 | 8 |
| 215+00 SB | CL | 6-2-97 | Untreated | 9 | 9 |
| 215+00 SB | 3 m RT | 6-2-97 | Untreated | 10 | 10 |
| 217+00 SB | CL | 6-2-97 | Untreated | 7 | 9 |
| 217+00 SB | 3 m RT | 6-2-97 | Untreated | 9 | 9 |
| 219+00 SB | CL | 6-2-97 | Untreated | 9 | 10 |
| 219+00 SB | 3 m LT | 6-2-97 | Untreated | 8 | 13 |
| 213+00 SB | CL | 6-4-97 | A.C. | 9 | 3 |
| 213+00 SB | 3 m LT | 6-4-97 | A.C. | 16 | 7 |
| 217+00 SB | CL | 6-4-97 | A.C. | 8 | 6 |
| 217+00 SB | 3 m RT | 6-4-97 | A.C. | 7 | 4 |
| 219+00 SB | CL | 6-4-97 | A.C. | 22 | 6 |
| 213+00 SB | CL | 6-5-97 | 1 Day A.C. | 10 | 5 |
| 213+00 SB | 3 m LT | 6-5-97 | 1 Day A.C. | 17 | 10 |
| 215+00 SB | CL | 6-5-97 | 1 Day A.C. | 15 | 7 |
| 215+00 SB | 3 m RT | 6-5-97 | 1 Day A.C. | 8 | 7 |
| 217+00 SB | CL | 6-5-97 | 1 Day A.C. | 16 | 5 |
| 217+00 SB | 3 m RT | 6-5-97 | 1 Day A.C. | 7 | 5 |
| 219+00 SB | CL | 6-5-97 | 1 Day A.C. | 28 | 12 |
| 213+00 SB | CL | 6-6-97 | 2 Days A.C. | 11 | 6 |
| 215+00 SB | CL | 6-6-97 | 2 Days A.C. | 11 | 10 |
| 217+00 SB | CL | 6-6-97 | 2 Days A.C. | 11 | 7 |
| 219+00 SB | CL | 6-6-97 | 2 Days A.C. | 17 | 10 |
| 213+00 SB | CL | 6-12-97 | 8 Days A.C. | 26 | 13 |
| 215+00 SB | CL | 6-12-97 | 8 Days A.C. | 24 | 6 |
| 217+00 SB | CL | 6-12-97 | 8 Days A.C. | 43 | 19 |
| 219+00 SB | CL | 6-12-97 | 8 Days A.C. | 31 | 19 |
| 213+00 SB | CL | 7-8-97 | 34 Days A.C. | 26 | 17 |
| 215+00 SB | CL | 7-8-97 | 34 Days A.C. | 22 | 12 |
| 217+00 SB | CL | 7-8-97 | 34 Days A.C. | 53 | 6 |
| 213+00 SB | CL | 8-20-97 | 78 Days A.C. | 18 | 15 |
| 215+00 SB | CL | 8-20-97 | 78 Days A.C. | 13 | 8 |
| 217+00 SB | CL | 8-20-97 | 78 Days A.C. | 26 | 10 |
| 219+00 SB | CL | 8-20-97 | 78 Days A.C. | 15 | 8 |

SB = Southbound Lanes  CL = Centerline  A.C. = After Compaction

## Project 2 DCP Test Summary

## Control Section

| Station | Test Location | Test Date | Description | IBV 0-150 mm | IBV 150-300 mm |
|---|---|---|---|---|---|
| | | | | | |
| 24+800 | RT | 10-23-97 | Untreated | 4 | 2 |
| 24+800 | LT | 10-23-97 | Untreated | 5 | 4 |
| 24+850 | RT | 10-23-97 | Untreated | 8 | 2 |
| 24+850 | LT | 10-23-97 | Untreated | 5 | 4 |
| 24+900 | RT | 10-23-97 | Untreated | 7 | 5 |
| 24+900 | LT | 10-23-97 | Untreated | 10 | 4 |
| 24+800 | RT | 10-30-97 | 6 Days A.C. | 17 | 28 |
| 24+800 | LT | 10-30-97 | 6 Days A.C. | 6 | 3 |
| 24+850 | RT | 10-30-97 | 6 Days A.C. | 7 | 7 |
| 24+850 | LT | 10-30-97 | 6 Days A.C. | 26 | 26 |
| 24+900 | RT | 10-30-97 | 6 Days A.C. | 28 | 29 |
| 24+900 | LT | 10-30-97 | 6 Days A.C. | 29 | 18 |
| 24+800 | RT | 12-6-97 | 52 Days A.C. | 13 | 12 |
| 24+800 | LT | 12-6-97 | 52 Days A.C. | 11 | 10 |
| 24+850 | RT | 12-6-97 | 52 Days A.C. | 18 | 36 |
| 24+850 | LT | 12-6-97 | 52 Days A.C. | 40 | 40 |
| 24+900 | RT | 12-6-97 | 52 Days A.C. | 18 | 19 |
| 24+800 | RT | 3-27-98 | 154 Days A.C. | 5 | 3 |
| 24+800 | LT | 3-27-98 | 154 Days A.C. | 10 | 15 |
| 24+850 | RT | 3-27-98 | 154 Days A.C. | 13 | 11 |
| 24+850 | LT | 3-27-98 | 154 Days A.C. | 33 | 65 |
| 24+900 | RT | 3-27-98 | 154 Days A.C. | 36 | 56 |
| 24+900 | LT | 3-27-98 | 154 Days A.C. | 19 | 17 |
| 24+800 | RT | 5-13-98 | 201 Days A.C. | 18 | 26 |
| 24+800 | LT | 5-13-98 | 201 Days A.C. | 15 | 13 |
| 24+850 | RT | 5-13-98 | 201 Days A.C. | 18 | 20 |
| 24+850 | LT | 5-13-98 | 201 Days A.C. | 29 | 65 |
| 24+900 | RT | 5-13-98 | 201 Days A.C. | 32 | 23 |
| 24+900 | LT | 5-13-98 | 201 Days A.C. | 18 | 33 |

RT or LT = 2-3 meters right or left of centerline     A.C. = After Compaction

## Project 2 DCP Test Summary (cont.)

### BHL Section

| Station | Test Location | Test Date | Description | IBV 0-150 mm | IBV 150-300 mm |
|---|---|---|---|---|---|
| | | | | | |
| 24+550 | RT | 10-23-97 | Untreated | 2 | 2 |
| 24+550 | LT | 10-23-97 | Untreated | 6 | 3 |
| 24+650 | RT | 10-23-97 | Untreated | 5 | 4 |
| 24+650 | LT | 10-23-97 | Untreated | 10 | 8 |
| 24+700 | RT | 10-23-97 | Untreated | 7 | 4 |
| 24+700 | LT | 10-23-97 | Untreated | 12 | 8 |
| 24+550 | RT | 10-24-97 | 1 Day A.C. | 14 | 6 |
| 24+550 | LT | 10-24-97 | 1 Day A.C. | 15 | 5 |
| 24+650 | RT | 10-24-97 | 1 Day A.C. | 13 | 13 |
| 24+650 | LT | 10-24-97 | 1 Day A.C. | 18 | 13 |
| 24+700 | RT | 10-24-97 | 1 Day A.C. | 16 | 8 |
| 24+700 | LT | 10-24-97 | 1 Day A.C. | 21 | 11 |
| 24+550 | RT | 10-30-97 | 7 Days A.C. | 8 | 9 |
| 24+550 | LT | 10-30-97 | 7 Days A.C. | 6 | 9 |
| 24+650 | RT | 10-30-97 | 7 Days A.C. | 17 | 25 |
| 24+650 | LT | 10-30-97 | 7 Days A.C. | 5 | 9 |
| 24+700 | RT | 10-30-97 | 7 Days A.C. | 16 | 22 |
| 24+700 | LT | 10-30-97 | 7 Days A.C. | 11 | 13 |
| 24+550 | RT | 12-6-97 | 53 Days A.C. | 10 | 8 |
| 24+550 | LT | 12-6-97 | 53 Days A.C. | 6 | 7 |
| 24+650 | RT | 12-6-97 | 53 Days A.C. | 32 | 49 |
| 24+650 | LT | 12-6-97 | 53 Days A.C. | 24 | 26 |
| 24+700 | RT | 12-6-97 | 53 Days A.C. | 20 | 40 |
| 24+700 | LT | 12-6-97 | 53 Days A.C. | 13 | 15 |
| 24+550 | RT | 3-27-98 | 155 Days A.C. | 10 | 10 |
| 24+550 | LT | 3-27-98 | 155 Days A.C. | 8 | 10 |
| 24+650 | RT | 3-27-98 | 155 Days A.C. | 32 | 53 |
| 24+650 | LT | 3-27-98 | 155 Days A.C. | 20 | 29 |
| 24+700 | RT | 3-27-98 | 155 Days A.C. | 15 | 11 |
| 24+700 | LT | 3-27-98 | 155 Days A.C. | 22 | 29 |
| 24+550 | RT | 5-13-98 | 202 Days A.C. | 15 | 13 |
| 24+550 | LT | 5-13-98 | 202 Days A.C. | 13 | 13 |
| 24+650 | RT | 5-13-98 | 202 Days A.C. | 20 | 28 |
| 24+650 | LT | 5-13-98 | 202 Days A.C. | 40 | 53 |
| 24+700 | RT | 5-13-98 | 202 Days A.C. | 18 | 26 |
| 24+700 | LT | 5-13-98 | 202 Days A.C. | 40 | 44 |

RT or LT = 2-3 meters right or left of centerline    A.C. = After Compaction

## Project 2 DCP Test Summary (cont.)

## CCFA Section

| Station | Test Location | Test Date | Description | IBV 0-150 mm | IBV 150-300 mm |
|---|---|---|---|---|---|
| | | | | | |
| 25+000 | RT | 10-23-97 | Untreated | 1 | 2 |
| 25+000 | LT | 10-23-97 | Untreated | 1 | 1 |
| 25+025 | RT | 10-23-97 | Untreated | 3 | 2 |
| 25+025 | LT | 10-23-97 | Untreated | 7 | 3 |
| 25+050 | RT | 10-23-97 | Untreated | 2 | 2 |
| 25+050 | LT | 10-23-97 | Untreated | 7 | 3 |
| 25+100 | RT | 10-23-97 | Untreated | 3 | 1 |
| 25+100 | LT | 10-23-97 | Untreated | 5 | 2 |
| 25+125 | RT | 10-23-97 | Untreated | 1 | 1 |
| 25+125 | LT | 10-23-97 | Untreated | 10 | 6 |
| 25+000 | RT | 10-24-97 | 18 Hours A.C. | 10 | 5 |
| 25+000 | LT | 10-24-97 | 18 Hours A.C. | 20 | 14 |
| 25+025 | RT | 10-24-97 | 18 Hours A.C. | 28 | 11 |
| 25+025 | LT | 10-24-97 | 18 Hours A.C. | 15 | 11 |
| 25+050 | RT | 10-24-97 | 18 Hours A.C. | 17 | 11 |
| 25+050 | LT | 10-24-97 | 18 Hours A.C. | 11 | 7 |
| 25+100 | RT | 10-24-97 | 18 Hours A.C. | 28 | 15 |
| 25+100 | CL | 10-24-97 | 18 Hours A.C. | 7 | 4 |
| 25+100 | LT | 10-24-97 | 18 Hours A.C. | 4 | 3 |
| 25+125 | RT | 10-24-97 | 18 Hours A.C. | 19 | 12 |
| 25+125 | LT | 10-24-97 | 18 Hours A.C. | 18 | 8 |
| 25+000 | RT | 10-30-97 | 7 Days A.C. | 5 | 11 |
| 25+000 | LT | 10-30-97 | 7 Days A.C. | 24 | 17 |
| 25+025 | RT | 10-30-97 | 7 Days A.C. | 8 | 13 |
| 25+025 | LT | 10-30-97 | 7 Days A.C. | 32 | 15 |
| 25+050 | RT | 10-30-97 | 7 Days A.C. | 11 | 8 |
| 25+050 | LT | 10-30-97 | 7 Days A.C. | 24 | - |
| 25+100 | RT | 10-30-97 | 7 Days A.C. | 4 | 4 |
| 25+100 | LT | 10-30-97 | 7 Days A.C. | 17 | 11 |
| 25+125 | RT | 10-30-97 | 7 Days A.C. | 15 | 15 |
| 25+125 | LT | 10-30-97 | 7 Days A.C. | 21 | 9 |
| 25+000 | RT | 12-16-97 | 53 Days A.C. | 6 | 12 |
| 25+000 | LT | 12-16-97 | 53 Days A.C. | 21 | 25 |
| 25+025 | RT | 12-16-97 | 53 Days A.C. | 17 | 17 |
| 25+025 | LT | 12-16-97 | 53 Days A.C. | 7 | 14 |
| 25+050 | RT | 12-16-97 | 53 Days A.C. | 10 | 16 |
| 25+050 | LT | 12-16-97 | 53 Days A.C. | 10 | 27 |
| 25+100 | RT | 12-16-97 | 53 Days A.C. | 11 | 11 |
| 25+100 | LT | 12-16-97 | 53 Days A.C. | 9 | 9 |
| 25+125 | RT | 12-16-97 | 53 Days A.C. | 18 | 18 |
| 25+125 | LT | 12-16-97 | 53 Days A.C. | 17 | 17 |

RT or LT = 2-3 meters right or left of centerline CL = Centerline A.C. = After Compaction

CCFA Section Continued on Next Page

## Project 2 DCP Test Summary

## CCFA Section (cont.)

| Station | Test Location | Test Date | Description | IBV 0-150 mm | IBV 150-300 mm |
|---|---|---|---|---|---|
| | | | | | |
| 25+000 | RT | 3-27-98 | 155 Days A.C. | 17 | 24 |
| 25+000 | LT | 3-27-98 | 155 Days A.C. | 20 | 49 |
| 25+025 | RT | 3-27-98 | 155 Days A.C. | 8 | 8 |
| 25+025 | LT | 3-27-98 | 155 Days A.C. | 26 | 33 |
| 25+050 | RT | 3-27-98 | 155 Days A.C. | 20 | 42 |
| 25+050 | LT | 3-27-98 | 155 Days A.C. | 22 | 36 |
| 25+100 | RT | 3-27-98 | 155 Days A.C. | 17 | 20 |
| 25+100 | LT | 3-27-98 | 155 Days A.C. | 20 | 22 |
| 25+125 | RT | 3-27-98 | 155 Days A.C. | 15 | 29 |
| 25+125 | LT | 3-27-98 | 155 Days A.C. | 26 | 29 |
| 25+000 | LT | 5-13-98 | 202 Days A.C. After Loading | 22 | 28 |
| 25+000 | RT | 5-13-98 | 202 Days A.C. | 33 | 40 |
| 25+025 | LT | 5-13-98 | 202 Days A.C. After Loading | 8 | 7 |
| 25+025 | RT | 5-13-98 | 202 Days A.C. | 24 | 33 |
| 25+050 | LT | 5-13-98 | 202 Days A.C. After Loading | 13 | 15 |
| 25+050 | RT | 5-13-98 | 202 Days A.C. | 17 | 53 |
| 25+100 | LT | 5-13-98 | 202 Days A.C. After Loading | 13 | 7 |
| 25+100 | RT | 5-13-98 | 202 Days A.C. | 22 | 18 |

RT or LT = 2-3 meters right or left of centerline A.C. = After Compaction

## Project 3 DCP Test Summary

## CCFA Section

| Station | Approximate Test Location | Test Date | Description | IBV 0-150 mm | IBV 150-300 mm |
|---|---|---|---|---|---|
| | | | | | |
| 101+850 | 3.5 m LT | 4-20-98 | Untreated | 1 | 8 |
| 101+850 | 3.5 m RT | 4-20-98 | Untreated | 2 | 7 |
| 101+900 | 3.5 m LT | 4-20-98 | Untreated | 2 | 8 |
| 101+900 | 3.5 m RT | 4-20-98 | Untreated | 4 | 5 |
| 101+950 | 3.5 m LT | 4-20-98 | Untreated | 1 | 8 |
| 101+950 | 3.5 m RT | 4-20-98 | Untreated | 1 | 5 |
| 102+000 | 3.5 m LT | 4-20-98 | Untreated | 2 | 9 |
| 102+000 | 3.5 m RT | 4-20-98 | Untreated | 3 | 8 |
| 102+050 | 3.5 m LT | 4-20-98 | Untreated | 2 | 5 |
| 102+050 | 3.5 m RT | 4-20-98 | Untreated | 2 | 6 |
| 101+848 | CL | 4-22-98 | 18 Hours A.C. | 13 | 24 |
| 101+850 | 3.5 m LT | 4-22-98 | 18 Hours A.C. | 2 | 8 |
| 101+850 | 3.5 m RT | 4-22-98 | 18 Hours A.C. | 3, 5 | 17, 20 |
| 101+875 | 3.5 m LT | 4-22-98 | 18 Hours A.C. | 7 | 11 |
| 101+875 | 3.5 m RT | 4-22-98 | 18 Hours A.C. | 5 | 17 |
| 101+900 | 3.5 m LT | 4-22-98 | 18 Hours A.C. | 4 | 17 |
| 101+900 | 3.5 m RT | 4-22-98 | 18 Hours A.C. | 4 | 17 |
| 101+950 | 3.5 m LT | 4-22-98 | 18 Hours A.C. | 5 | 9 |
| 101+950 | 3.5 m RT | 4-22-98 | 18 Hours A.C. | 5 | 17 |
| 102+000 | 3.5 m LT | 4-22-98 | 18 Hours A.C. | 4 | 10 |
| 102+000 | 3.5 m RT | 4-22-98 | 18 Hours A.C. | 4 | 15 |
| 102+050 | 3.5 m LT | 4-22-98 | 18 Hours A.C. | 4 | 10 |
| 102+050 | 3.5 m RT | 4-22-98 | 18 Hours A.C. | 11 | 10 |
| 101+850 | 3.5 m LT | 4-28-98 | 7 Days A.C. | 17 | 18 |
| 101+850 | CL | 4-28-98 | 7 Days A.C. | 4 | 11 |
| 101+850 | 3.5 m RT | 4-28-98 | 7 Days A.C. | 17 | 40 |
| 101+900 | 3.5 m LT | 4-28-98 | 7 Days A.C. | 42 | 32 |
| 101+900 | CL | 4-28-98 | 7 Days A.C. | 3 | 8 |
| 101+900 | 3.5 m RT | 4-28-98 | 7 Days A.C. | 20 | 42 |
| 101+950 | 3.5 m LT | 4-28-98 | 7 Days A.C. | 29 | 36 |
| 101+950 | CL | 4-28-98 | 7 Days A.C. | 2 | 10 |
| 101+950 | 3.5 m RT | 4-28-98 | 7 Days A.C. | 8, 4 | 28, 15 |
| 102+000 | 3.5 m LT | 4-28-98 | 7 Days A.C. | 33 | 26 |
| 102+000 | CL | 4-28-98 | 7 Days A.C. | 4, 3 | 13, 13 |
| 102+000 | 3.5 m RT | 4-28-98 | 7 Days A.C. | 5 | 10 |
| 102+050 | 3.5 m LT | 4-28-98 | 7 Days A.C. | 20 | 18 |
| 102+050 | CL | 4-28-98 | 7 Days A.C. | 26 | 18 |
| 102+050 | 3.5 m RT | 4-28-98 | 7 Days A.C. | 8 | 8 |
| 101+850 | CL | 5-11-98 | 20 Days A.C. | 5 | 20 |
| 101+900 | CL | 5-11-98 | 20 Days A.C. | 15 | 32 |
| 101+950 | CL | 5-11-98 | 20 Days A.C. | 5 | 20 |
| 102+000 | CL | 5-11-98 | 20 Days A.C. | 8 | 26 |
| 102+000 | 3.5 m RT | 5-11-98 | 20 Days A.C. | 5 | 15 |
| 102+050 | CL | 5-11-98 | 20 Days A.C. | 32 | 40 |
| 102+050 | 3.5 m LT | 5-11-98 | 20 Days A.C. | 36 | 33 |

CL = Centerline  A.C. = After Compaction

# Appendix E

## Falling Weight Deflectometer Data

## Project 1 Deflection Statistics

| Section | Test Date | Pavement Temp. °C | D0*, µm | | Area, mm | | $E_{RI}$, MPa | |
|---|---|---|---|---|---|---|---|---|
| | | | Average | COV | Average | COV | Average | COV |
| | | | | | | | | |
| BHL | 11/20/97 | 3 | 86 | 0.11 | 724 | 0.03 | 103 | 0.03 |
| BHL | 4/21/98 | 6 | 107 | 0.09 | 709 | 0.02 | 93 | 0.05 |
| BHL | 3/25/99 | 7 | 107 | 0.10 | 734 | 0.02 | 89 | 0.05 |
| BHL | 5/11/00 | 22 | 160 | 0.13 | 688 | 0.03 | 71 | 0.08 |
| NB LKD | 11/20/97 | 3 | 89 | 0.12 | 724 | 0.04 | 101 | 0.06 |
| NB LKD | 4/21/98 | 6 | 102 | 0.13 | 709 | 0.04 | 96 | 0.07 |
| NB LKD | 3/25/99 | 7 | 104 | 0.15 | 732 | 0.03 | 92 | 0.07 |
| NB LKD | 5/11/00 | 22 | 157 | 0.13 | 678 | 0.04 | 75 | 0.07 |
| CCFA | 11/20/97 | 3 | 89 | 0.07 | 721 | 0.02 | 101 | 0.04 |
| CCFA | 4/21/98 | 6 | 104 | 0.08 | 714 | 0.01 | 94 | 0.05 |
| CCFA | 3/25/99 | 7 | 112 | 0.06 | 724 | 0.02 | 88 | 0.05 |
| CCFA | 5/11/00 | 22 | 163 | 0.06 | 665 | 0.02 | 74 | 0.06 |
| SB LKD | 11/20/97 | 3 | 86 | 0.12 | 714 | 0.05 | 105 | 0.06 |
| SB LKD | 4/21/98 | 6 | 104 | 0.08 | 714 | 0.02 | 94 | 0.04 |
| SB LKD | 3/25/99 | 7 | 112 | 0.08 | 734 | 0.02 | 86 | 0.06 |
| SB LKD | 5/11/00 | 22 | 175 | 0.08 | 676 | 0.02 | 68 | 0.07 |

D0* = Deflection below the load plate normalized to a 40 kN load.

## Project 3 Deflection Statistics

| Section | Test Date | Pavement Temp. °C | D0*, µm | | Area, mm | | $E_{RI}$, MPa | |
|---|---|---|---|---|---|---|---|---|
| | | | Average | COV | Average | COV | Average | COV |
| | | | | | | | | |
| Control | 7/20/98 | 45 | 357 | 0.09 | 483 | 0.03 | 75 | 0.05 |
| Control | 4/6/99 | 11 | 124 | 0.11 | 689 | 0.03 | 92 | 0.04 |
| Control | 5/10/00 | 18 | 130 | 0.10 | 663 | 0.03 | 87 | 0.04 |
| CCFA | 7/20/99 | 45 | 323 | 0.06 | 483 | 0.04 | 75 | 0.05 |
| CCFA | 4/6/99 | 11 | 120 | 0.08 | 698 | 0.02 | 92 | 0.03 |
| CCFA | 5/10/00 | 18 | 120 | 0.05 | 682 | 0.02 | 88 | 0.03 |

D0* = Deflection below the load plate normalized to a 40 kN load.

# Appendix F

## Recommended Mix Design Procedures and Specifications

**RECOMMENDED LABORATORY DESIGN PROCEDURES**
**For**
**FLY ASH MODIFIED SOILS**

Scope  These methods describe the preparation and testing of fly ash - soil mixtures for the purpose of recommending a design fly ash content for construction and also for evaluating the properties of the mixture.

Apparatus  Equipment and materials required to perform Methods A (except for the oven) and B of the Department's "Laboratory Design Procedures for Lime Stabilized/Lime Modified Soils" outlined in the Geotechnical Manual.  Method A equipment is used to evaluate granular soil – fly ash mixtures.  Method B equipment is used to evaluate cohesive soil – fly ash mixtures.

Samples  Samples of soil and fly ash shall be provided as specified in the Specification for "Fly Ash Modified Soils."

Method A - Granular Soils

1. Dry Preparation of Soil - The soil, as received, shall be prepared for test according to AASHTO T 87.

2. Compaction - Obtain the standard dry density and optimum moisture content of the natural soil and soil fly-ash mixtures according to AASHTO T 99, Method C.

3. Soil - Fly Ash Mixtures

   Add increments of 5 percent fly ash to the soil on a dry weight basis. The fly ash content shall not exceed 20% by dry weight.

   Dry mix enough fly ash and soil for one AASHTO T 99 compaction sample until a homogeneous mixture is obtained.  Gradually add the compaction water.  Continue mixing for 2 minutes.  Place the resulting mixture in a covered pan.  Prepare a new soil - fly ash mixture for each sample.

   Compact the soil-fly ash mixture one hour after mixing.

   Repeat the compaction procedures, for each sample, until the moisture-density relationships are obtained for a series of at least three fly ash contents.

5. Preparation of Test Specimens – Four test specimens at each trial fly-ash content shall be molded at OMC and SDD using the mixing procedures described above.  Each specimen shall be compacted dynamically, in the 51 mm x 102 mm mold, in three equal layers.  The number of blows per layer, with the sliding hammer, shall be adjusted to obtain the SDD.  It is important that each of the first two lifts be scarified to promote bonding.  The compacted sample is then trimmed, extracted, weighed, and the mass is recorded.

6. Curing of Specimens – Place the fly-ash treated soil specimens in sealed containers and cure at room temperature for a minimum of 24 hours.  A 48 hour curing period may also be used depending on mix design objectives.

7. Compression Testing – Test each specimen to failure, at a constant rate of 1.27 mm per minute. The compressive strength shall be determined according to AASHTO T 208. Obtain a moisture sample from each failed specimen. The resulting moisture content shall be used to calculate the actual dry density of each specimen. The moisture content shall be determined according to AASHTO T 265.

8. Determine the Design Fly Ash Content – The minimum fly ash content shall be designated as the fly ash content which provides a minimum compressive strength of 310 kPa or more. Increase the minimum fly ash content by 1 percent to obtain the design fly ash content to offset blowing, uneven distribution, and other factors.

<u>Method B – Cohesisve Soils</u>

1. Dry Preparation of Soil - The soil, as received, shall be prepared for testing according to AASHTO T 87.

2. Compaction – Obtain the standard dry density and optimum moisture content of the natural soil and soil fly-ash mixtures according to AASHTO T 99, Method C.

3. IBV Testing – Immediately after compaction, the IBV test shall be conducted according to Geotechnical Manual Attachment II-A Section 2. After the IBV test, the sample shall be extracted from the mold and a specimen taken for moisture content determination according to AASHTO T 99.

4. Soil - Fly Ash Mixtures

   Add increments of 5 percent fly ash to the soil on a dry weight basis. The fly ash content shall not exceed 20% by dry weight.

   Dry mix enough fly ash and soil for one AASHTO T 99 compaction sample until a homogeneous mixture is obtained. Gradually add the compaction water. Continue mixing for 2 minutes. Place the resulting mixture in a covered pan. Prepare a new soil - fly ash mixture for each sample.

   Compact the soil-fly ash mixture one hour after mixing, and perform the IBV test.

   Repeat the compaction and IBV testing procedures, for each sample, until the moisture-density-IBV relationships are obtained for a series of at least three fly ash contents.

5. Evaluation of Test Results - Plot the dry density and IBV versus moisture content for the soil, and for each level of soil-fly ash content investigated.

6. Determine the Design Fly Ash Content - The minimum fly ash content shall be designated as the fly ash content which provides an IBV of 10.0 percent or more, for the anticipated field moistures. Increase the minimum fly ash content by 1 percent to obtain the design fly ash content to offset blowing, uneven distribution, and other factors.

   NOTE: For silty soils with a clay content less than approximately 15%, Method B mix design procedures may yield artificially high IBVs. Method A compressive strength test procedures should be used to verify IBV results at the design fly ash content determined using Method B. If a significant discrepancy between IBV and compressive strength results exists, Method A mix design procedures should be used to determine the design fly ash content.

7. IBR (soaked) Test - Obtain the bearing value and percent swell according to Geotechnical Manual Attachment II-A Section 1. Conduct the test with the minimum fly ash content at standard dry density and optimum moisture content. The amount of swell, after soaking for 96 hours, shall not be greater than 4.0%.

8. Cured Bearing Value (optional) - Curing of the compacted fly ash - soil mixture may be required to obtain the minimum 10.0 percent IBV value. Compact a sample with a moisture content close to anticipated field conditions according to AASHTO T 99. The compacted sample shall be sealed in the mold to prevent moisture loss during the curing period. After a curing period of 48 hours, penetrate the sample and obtain a moisture content.

Determining Minimum Construction Moisture Requirements

The addition of fly ash at the required treatment rates reduces the net amount of water available for hydration. This reduction in moisture content shall be estimated using the following equation:

Moisture Reduction, % = $3.2 \times \{OMC - [100W_w / (W_s + W_{CCFA})]\}$

Where: OMC = Optimum moisture content of the untreated soil in percent
$W_w$ = OMC/100 multiplied by the untreated soil standard dry density in kg/m³ (pcf)
$W_s$ = Standard dry density of the untreated soil in kg/m³ (pcf) / 1 m³ (1 ft³)
$W_{CCFA}$ = Design treatment rate per cubic meter in kilograms (rate per ft³ in pounds)

The minimum moisture content requirement shall be determined by adding the moisture reduction calculated above to the optimum moisture content of the treated soil at the design fly ash content.

Report

The report shall contain the information required by Method A or B of the Department's "Laboratory Design Procedures for Lime Stabilized/Lime Modified Soils." The minimum moisture content requirement shall also be reported. Cured IBV and curing period shall be reported when optional cured IBV testing is performed. The curing period for compressive strength test shall be reported where applicable.

**Recommended Material Specifications for By-Product Hydrated Lime for Lime Modified Soils**

**1012.0x. By-Product Hydrated Lime for Lime Modified Soils.** When used in lime modified soils, by-product hydrated lime (hydrator tailings) shall conform to the following requirements:

| | |
|---|---|
| (a) Total calcium and magnesium oxides (nonvolatile basis) min. percent | 90 |
| (b) Available calcium hydroxide (rapid sugar test, ASTM C 25) plus total MgO content calculated to be equivalent $Ca(OH)_2$ min. percent | 70 |
| (c) As received loss on ignition (carbon dioxide plus moisture, combined and free), max. percent | 25 |
| (d) Free water (as-received basis), max. percent | 4 |

(e) Residue – The sieve analysis shall be as follows

| Sieve | Maximum Percent Retained |
|---|---|
| 4.75 mm (No. 4) | 0 |
| 600 µm (No. 30) | 10 |
| 150 µm (No. 100) | 60 |

**Recommended Revisions to Section 302 of the Standard Specifications to Include BHL**

Article 302.02 – Add “By-Product Hydrated Lime for Lime Modified Soils.”

Article 302.08 – Add “Note 3: Compaction of soils treated with By-Product Hydrated Lime shall be delayed a minimum of 24 hours.” after the first paragraph.

**Recommended Revisions to Section 1010 of the Standard Specifications to Include Soil Modification with CCFA**

Add Article 1010.0X “**Modified Soils**. The fly ash shall meet the requirements of AASHTO M 295, Class C except for the following:

(a) Loss-on-Ignition shall be less than or equal to 10 percent.
(b) Supplementary Optional Chemical Requirements shall not apply.
(c) Physical Requirements shall not apply.
(d) The material retained on the 0.150 mm sieve shall not exceed 15%.

Fly ash shall not be dampened for the purpose of transportation.”

**RECOMMENDED SPECIFICATION**
**for**
**FLY ASH MODIFIED SOILS**

**x.01 Description.** This work shall consist of the construction of a fly ash modified soil layer composed of soil, fly ash, and water.

**x.02 Materials.** Materials shall meet the requirements of the following Articles of Section 1000 - Materials:

| Item | Article/Section |
|---|---|
| (a) Water | 1002 |
| (b) Fly Ash | 1010.0X |

**x.03 Equipment.** Equipment shall meet the requirements of the following Articles of Section 1100 - Equipment:

| Item | Article/Section |
|---|---|
| (a) Rollers (Note 1) | 1101.01 |
| (b) Distributor (Note 2) | |
| (c) Rotary Speed Mixer | 1101.06 |
| (d) Disk Harrow | 1101.02 |
| (e) Subgrade Planer | 1103.08 |
| (f) Subgrade Machine | 1103.09 |
| (g) Heavy Subgrade Template | 1103.10 |
| (h) Water Supply Equipment | 1103.11 |

Note 1. Three-wheel rollers and tandem rollers, when used, shall weigh not less than 5.5 metric tons (6 tons) nor more than 11 metric tons (12 tons) and shall have a compression on the drive wheels of not less than 35 N/mm (190 lbs. per inch) nor more than 70 N/mm (400 lbs. per inch) width of roller.

Note 2. Distributor shall capable of spreading fly ash uniformly over the area to be modified as approved by the Engineer.

## CONSTRUCTION REQUIREMENTS

**x.04 General.** The fly ash modified soil shall be constructed only when the temperature of the soil, measured 150 mm (6 inches) below the surface, is above 7 °C (45 °F), and the ambient air temperature is above 4 °C (40 °F). Fly ash shall not be applied to or mixed with frozen soil. The amount of fly ash modified soil constructed shall be limited to that which can be covered with subbase, base or pavement within the same construction season, unless otherwise permitted by the Engineer.

**x.05 Proportioning.**

(a) Samples. The Contractor, at his/her own expense, shall provide a minimum of 7 kg (15 lb.) of fly ash and 45 kg (100 lb.) of soil proposed to be used at least 30 days prior to the construction of the fly ash modified soils.

(b) Mix Design. Fly ash will be proportioned within a range of 10 - 20 percent of soil (oven dry basis). The required proportion of fly ash will be established by the Engineer prior to construction, using samples of the proposed soil and fly ash, and the Department's “Laboratory Design Procedures for Fly Ash Modified Subgrade.” The Engineer reserves the right to make such adjustments of fly ash proportioning as are considered necessary during the progress of the work within the range specified, without additional compensation to the Contractor.

The source of fly ash shall not be changed during the progress of the work without permission of the Engineer.

**x.06 Spreading of Fly Ash.** The fly ash shall be distributed uniformly over the subgrade surface. A probe shall be used to randomly check the thickness of fly ash. The Engineer may reject any procedure which does not provide even distribution of fly ash. The Engineer may require additional fly ash to be spread to correct uneven distribution at no cost to the Department.

Fly ash shall not be applied when wind conditions are such that blowing fly ash becomes objectionable to adjacent property owners or creates a hazard to traffic on adjacent highways.

The spreading of fly ash shall be limited to that amount which can be incorporated into the soil within the same working day. In the event that rain wets fly ash prior to mixing, the Engineer may require additional fly ash to be spread at no cost to the Department.

The surface of the grade shall be scarified or disked to a minimum depth of 150 mm (6 inches) following fly ash distribution. Disking or scarification is not required for granular soils.

**x.07 Mixing.** The fly ash, soil, and water (if necessary) shall be thoroughly blended by a rotary speed mixer. Water shall be added prior to the mixing operation in a sufficient quantity to bring the moisture content of the soil-fly ash mixture to the minimum determined during the mix design. Water shall be added either 24 hours prior to spreading fly ash, or directly in front of the rotary speed mixer.

If more than one pass of the rotary speed mixer is required to obtain a homogenous mixture, 25 percent of the specified fly ash quantity shall be spread and mixed as a preparation for the final pass of the rotary speed mixer. The remaining specified quantity of fly ash shall be spread prior to the final pass of the rotary speed mixer. Mixing shall continue until approximately 75 percent of the mixture is smaller than 25 mm (1 inch). The loose thickness of a single fly ash modified layer shall not exceed 350 mm (14 inches).

**x.08 Compaction.** Compaction shall be completed no later than 1 hour after mixing begins.

Compaction shall be continued until the fly ash modified layer has a density of not less than 95 percent of the standard dry density of the fly ash treated soil. The standard dry density of the fly ash treated soil shall be determined according to the Department's "Laboratory Design Procedures for Fly Ash Modified Subgrade." The field in-place dry density will be determined by the Engineer according to AASHTO T 191, or Illinois Modified AASHTO T 310 (Direct Transmission Density/Backscatter Moisture), or by other methods approved by the Engineer.

**x.09 Finishing and Curing.** The final lift of fly ash modification shall be constructed approximately to the grade shown on the plans before spreading the fly ash. The final lift of fly ash modification shall be no less than 150 mm (6 inches) thick when compacted.

The fly ash modified subgrade shall be cured for a minimum of 24 hours. During the curing period, the moisture content of the modified soil shall be maintained at optimum, as determined according to the Department's "Laboratory Mix Design Procedure for Fly Ash Modified Soils," by sprinkling with water or other method approved by the Engineer. The ambient air temperature shall be above 4 °C (40 °F) during curing. No traffic shall be permitted on the fly ash modified subgrade during the curing period. The surface shall be shaped to the required lines, grades, and cross section following the curing period.

For bituminous concrete base course and pavement (full-depth), and portland cement concrete base course and pavement construction, the surface of the fly ash modified soil shall be brought to true shape and correct elevation according to Article 301.06, except that well compacted earth shall not be used to fill low areas.

**x.10 Method of Measurement.**

(a) Contract Quantities. The requirements for the use of contract quantities shall conform to Article 202.07(a).

(b) Measured Quantities. Processing fly ash modified soils will be measured in place and the area computed in square meters (square yards). The width for measurement will be as shown on the plans.

Water used will be measured in units of 1000 L (1000 gallons). A weigh ticket or meter ticket for each truck load shall be furnished to the Engineer. Scales or meters shall be approved by the Engineer.

Fly ash will be measured for payment in metric tons (tons). The fly ash shall be measured in trucks or freight cars. The Contractor shall furnish or arrange for use of scales of a type approved by the Engineer. If the fly ash is shipped in trucks, it shall be measured at the place of loading, at the place of unloading, or at such other place as the Engineer may designate. The Engineer may accept original signed freight bills in lieu of determining the mass (weight).

Should the Contractor's method of construction require extra earth excavation or embankment due to requiring more than one lift to construct the fly ash modified soil layer as shown on the plans, this extra earth excavation and embankment will not be measured for payment.

**x.11 Basis of Payment.** This work will be paid for at the contract unit price per square meter (square yard) for PROCESSING FLY ASH MODIFIED SOILS of the thickness specified, per unit for WATER, and per metric ton (ton) for FLY ASH.